FINAL REPORT

Solar Air Heating Metal Roofing For Reroofing, New Construction, and Retrofit

ESTCP Project EW-201148

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American Solar, Inc.

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14. ABSTRACT This project installed a solar air heating metal roof on the Gaffney Fitness Facility at Fort Meade, Maryland, to demonstrate a better, longer life roof that delivers solar heat to the building and document the design, construction, and performance of the roof and energy savings.

15. SUBJECT TERMS
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LIST OF ACRONYMS

A&E – Architecture and Engineering
ARRA – American Recovery and Reinvestment Act
ASHRAE – The American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME – The American Society of Mechanical Engineers
ASI – American Solar, Inc.
BLCC – Building Life-Cycle Cost
BTU – British Thermal Unit = the heat energy required to raise 1 pound of water 1 ° F
BUR – Built-Up Roof – Multiple alternating layers of liquid asphalt and 'felt paper" that from a weathertight roof
CERL – Civil Energy Research Laboratory
CRADA – Cooperative Research and Development Agreement
DOD – Department of Defense
ECIP – Energy Conservation Investment Program
ESTCP- Environmental Security Technology Certification Program
FDA – Food and Drug Administration
HVAC – Heating, Ventilation and Air-Conditioning
NIST – National Institute for Standards and Technology
PEX – Cross linked polyethylene use to make flexible tubing for plumbing uses
PVDF -- Polyvinylidene fluoride roof coating
SRCC – Solar Rating and Certification Corporation
SESPC – Super Energy Savings Performance Contracts
USGS – United States Geological Survey
UFC – Unified Facility Criteria

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Joseph Scott Morgan, Principal Engineer, formerly with American Solar, Inc.
Dave Gochenaur, CEO, and Jerry Copp, Project Supervisor, Merit Builders, Inc.
Carlo LaPorta, Principal, and Scott Woycio, Project Manager, Capital Sun Group, LLC

Bill Stein with Engineer Research and Development Center - Construction Engineering Research Laboratory

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EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION:

DOD has nearly 2 billion square feet of building "under roof" that require "heating" for space heat, water heat, and equipment heat. DOD's total Operations and Maintenance expenses for all buildings are very high, but two of the largest recurring expenses in DOD facility operations are:

1. The annual "heating" energy bills, ~$1.28/square foot of occupied space/year
2. The infrequent, but expensive, re-roofing of buildings, ~$0.67/square foot of roof/year (~$10/sqft of roof about every 15th year).

With over 570,000 buildings and 1.9 billion square feet of occupied space, annual "heating" bills are $2.4 billion (2006) out of a $4 billion total energy bill. Roofing expenses are about $640 million per year.

To reduce the impact of energy used to heat buildings, American Solar, Inc. demonstrated the benefits gained by using a Solar Air Heating Metal Roof in place of continuing to repair and replace built up roofs at the Gaffney Fitness Center located at Ft. Meade, Md. The innovative solar air heating metal roofing system uses conventional, weathertight, metal roofing in a traditional, code approved, manner to provide a long life (40 year), weathertight roof and a solar air heating collector. The solar metal roof saves over $5,000/yr, and over $189,000 over the 30 year life of the 9,275 square foot roof.

The innovative combined use of the roof panel as both the roof and the solar collector surface greatly reduces the cost of collecting solar energy for heating. The collection of solar heat via solar heated air makes the system extremely efficient and productive at air heating, (the largest building heating load) and provides sufficiently high solar air temperatures for water preheating from a conventional air to water heating coil, placed in an easily maintainable location.

A solar air heating roof was installed over the worn out roof of the Fitness Center. The testing of the solar roof showed that the system can consistently provide solar heat to the outside air intakes and directly to the building and hot water system, and that it reduces unwanted heat loss and gain through the roof. Testing and analysis created a 'first of its kind' analytical performance model for unglazed solar air heating metal roofs.

EXPERIMENTAL APPROACH: A set of temperature sensors were installed within and around the new solar roof. This included:

- a set installed in the outlet from the solar roof to the outdoor air intakes of the air handler for the gym and
- a set installed at the solar air to water heat exchanger plenum which can also supply solar air directly to the gym.

Temperature readings were taken every 15 minutes from late June 2012 thru late January 2013 along with other readings. Data available from local weather stations with time stamped solar insolation, wind speed, and ambient temperature data were used to track environmental conditions.

TECHNOLOGY DESCRIPTION: With the solar air heating metal roof, the metal roof panels heat up to about 80 degrees F above ambient temperatures during daylight hours, heating the air immediately below the metal panel. By the simple application of conventional fans and ducts, the solar heated air is pulled from beneath the metal roof and delivered to the building to serve a variety of useful purposes.

The specific project:

- re-roofed a badly worn and patched built up roof with a long life metal roof,
- provides insulation to keep the old, covered roof warmer in winter and cooler in summer, and
- delivers solar heated air used for:
    - outdoor air preheat of ventilation air during the heating season
    - direct space heat of the gym during the heating season, and
    - domestic water preheating for showers and sinks, year round.

DEMONSTRATION RESULTS: The solar roof demonstrated the capacity to provide weather protection comparable to any long life metal roof, to keep the building warmer in winter and cooler in summer, and to deliver heat via outside air preheat, direct space heat, and water preheat. The combined energy and cost savings provide a net positive savings for the building compared to the continued installation of a series of several Built Up Roofs. In the best case, the cost savings are enough to pay for the re-roof, which can not be said for any other non-solar roof. A 'first of its kind' predictive model was developed as part of the project. The model enables the prediction of solar roof temperatures and prediction of heat energy flows from solar heated air and water that can be applied to any other building using local solar and weather data.

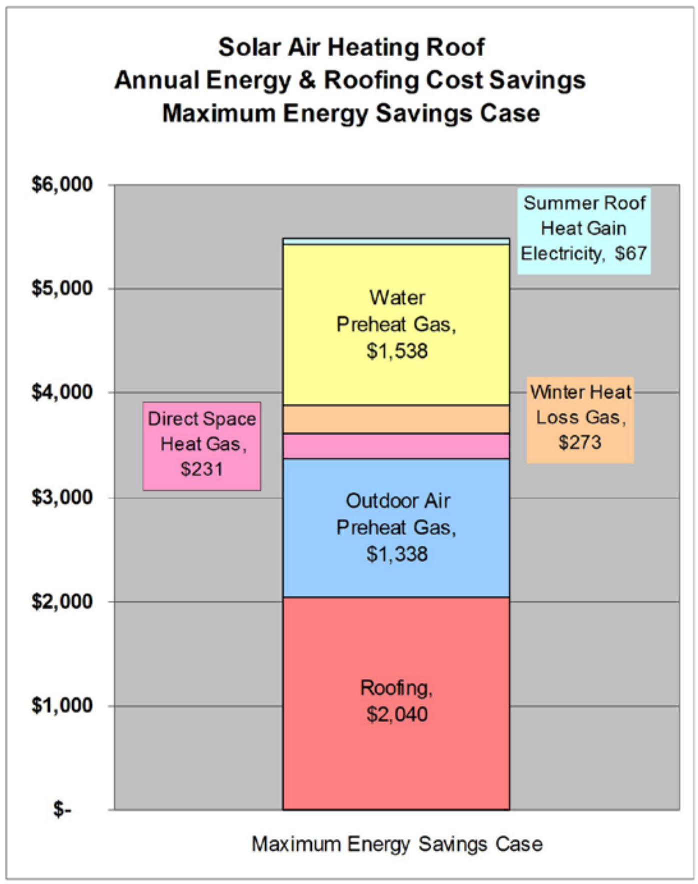

Figure Error! No text of specified style in document.**E-1, Solar Roof Annual Energy & Roof Cost Savings**

IMPLEMENTATION ISSUES: The solar air heating roof provides a simple, rugged, reliable, long life roof and solar heating system. There is flexibility in applying the systems to various roof slopes, orientations, colors and separation from the load being served. To minimize cost and maximize the return on investment, the simplest mounting structure consistent with roofing needs should be used above an existing built up roof. Solar air heat recovery from the roof should occur as close as possible to the load being served to minimize long insulated duct runs. Where water heating is to be accomplished, the 'wet' components should be installed in spaces that will provide freeze protection. Tuning the solar heating system is possible using predictive performance models and local utility rates to ensure that the system operates only during hours when positive cost savings will be generated.

PERFORMANCE OBJECTIVES: The abbreviated performance objectives in the following tables show the most significant results of the demonstration at the Gaffney Fitness Center. The system showed savings of up to 25% in roofing cost, up to 20% in heating cost, 15% in greenhouse gas emissions, and heat production of up to 60 BTU/hour/sqft of roof. The metal roofing will for 40 years, outlasting two built up roofs and the simple mechanical fans and pump will perform reliably for decades.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Solar energy delivery to air	Million BTU of renewable heat energy delivered	Temperature and flow of solar air	Peak heat transfer to air, 50 Btu/sqft/hr	Peak 47-60 Btu/sqft roof/hr
Solar energy delivery to water	Million BTU of energy to the domestic hot water	Temperature and flow of solar air, solar water heating	Average 2,000 BTU/sqft/month April to October	5,851 BTU/sqft/month April to October
Renewable Energy Use	% of Energy Use By Gaffney Gym	Monthly Solar Energy Delivered	7% of Building Heat Energy Use	10- 19% of Heat Energy Use
System Economics	Roof Cost Savings $ Energy Cost Savings $, Years	Dollar costs, discount rate, usable life, Energy Cost Savings	5% savings in life cycle roof costs, 7% savings in life cycle heating costs	Up to 25% roof cost savings, 8-20% heating cost savings
Direct Greenhouse Emissions	Direct fossil fuel GHG emissions (metric tons)	GHG based on source of energy	7% GHG savings	Up to 15% GHG savings

Table E-1 Quantitative Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Qualitative Performance Objectives				
System maintenance	Report on Roof Maintenance cycle	Years to repair or replace roof	30 year solar roof repaint 40 year solar roof life	Roof Maintenance Cycle Report
System Reliability	Percent Time System performs as designed	Run Time / Downtime hours	5% Downtime Hours 95% Run time Hour	2% downtime hours 98% runtime hours

Table E-2 Qualitative Objectives

1.0 INTRODUCTION

Energy managers throughout DoD are confronted with the tasks of rapidly reducing energy intensities while simultaneously deploying new, cost effective, low maintenance technologies. Striking a balance between the goals of technology integration, life cycle cost savings and carbon footprint reduction is challenging. The demonstration of the Solar Air Heating Roof system proved that a single roofing system can help meet all these goals.

1.1 BACKGROUND

DOD has nearly 2 billion square feet of building "under roof" that require "heating" for space heat, water heat, and equipment heat. DOD's total Operations and Maintenance expenses for all buildings are very high, but two of the largest recurring expenses in DOD facility operations are:

1. The annual "heating" energy bills, ~$1.28/square foot of occupied space/year (2006)
2. The infrequent, but expensive, re-roofing of buildings, ~$0.67/square foot of roof/year (~$10-15/sqft of roof about every 15th year).

With over 570,000 buildings and 1.9 billion square feet of occupied space, annual "heating" bills are $2.4 billion (2006) out of a $4 billion total energy bill. Roofing bills are on the order of $640 million per year. Reducing these costs will leave more money for other defense needs.

Typically, roofing and heating systems are separately purchased, installed, and maintained. Often, the roofing system is installed based on lowest first cost provided that it achieves a 15 year life. This has resulted in millions of square feet of Built Up Roof or membrane roof being installed. After about 15 years the roof is torn off and transported to a landfill where it is dumped and buried, where the asphalt and polymer material are not likely to decompose. Back at the building another roof is installed starting the cycle over again.

In contrast, metal roofing has a nominal service life of 40 years, can be recycled when removed and is recognized as more lifecycle cost effective, but it is higher first cost. The typical purchase of heating energy systems ignores the potential heating contribution of the roof, because there is no way to harvest heating energy from a built up roof.

In 2001 American Solar began designing and installing solar air heating roofs. These roofs are installed on residential, commercial, and government buildings and deliver long life metal roofing and significant quantities of heat energy. They do so at lower life cycle cost than using conventional roofing and heating systems alone. The largest of these roofs are installed on buildings at Army and Air Force installation.

The solar air heating roof system is a weathertight, code approved, metal roof that can be installed directly over an existing, worn out roof. A shallow air space is created under the metal roof panel. When the sun hits the metal panel, the panel is heated to as much as 80 degrees F above outside air temperatures. Using simple fans and ducts, the solar heated air is recovered from the solar air space and delivered to the building for a variety of useful purposes. The most common purposes are outdoor air preheat, direct space heat, and water preheat.

For this demonstration, American Solar installed 9,275 square feet of solar air heating roof over existing built up roofs on the Gaffney Fitness Center, located at Ft. Meade, MD. A simple before and after perspective of the roof is shown in Figure 1. A 7,715 square foot section was installed over the sloped built up roof above the gym. Another 1,560 square feet of solar roof was installed as a continuation of the roof, above a flat built up roof, creating a large mechanical room.

Solar fans were installed to draw air from the roof and deliver it to the outdoor air intake of an air handler and to the air to water heat exchanger and then directly to the gym.

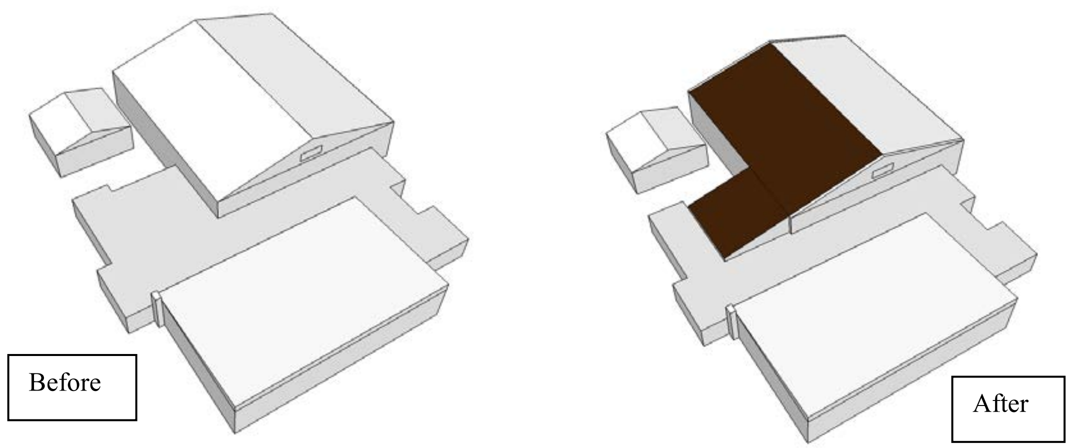

Figure 1 Before and After

1.2 OBJECTIVES OF THE DEMONSTRATION

The project's two overarching objectives were to reduce a building's energy costs while demonstrating a cost effective roofing system that significantly reduces the carbon footprint and life cycle costs found in traditional roofing materials.

Beyond these broad objectives, were many specific Quantitative and Qualitative objectives in the testing, analysis, and reporting that were identified in the Demonstration Plan for the project.

Among the Quantitative Objectives:
Validate:

- the solar energy delivery of the roof to heating air
- the solar energy delivery to the domestic hot water system
- the renewable energy delivery to the building
- the economic performance of the system

Document:

- the greenhouse gas emission reductions

- the performance as it compares to a reflective "Cool Roof"
- the performance of a radiant barrier/ heat recovery system installed in the re-roofed attic of an office building at Marine Corps Air Station, Beaufort, SC

Among the Qualitative Objectives:
Report on:

- mechanical system maintenance and roof maintenance cycle
- system reliability including percent downtime.

Because the application of this solar roofing system is relatively new, there is little knowledge of it across the design and construction community. The documented and validated performance of this project provides confidence that these systems can reduce carbon emissions and save around $0.50 per square foot of roof per year, by using renewable solar energy gathered from a long life, low maintenance roof.

1.3 REGULATORY DRIVERS

Existing Federal law, Executive Orders, and Agency implementing directives and instructions require the reduction of energy use and greenhouse gas emissions, increased use of renewable energy and sustainable building design.

The most relevant of these requirements are:
A reduction in energy use per square foot by 30% by 2015 compared to 2003.
An increase in renewable energy use from new renewable energy sources
A reduction in greenhouse gas emissions and
An increase in sustainable building design, construction, and operations by pursuing cost-effective, innovative strategies to minimize consumption of energy and materials.

Three prominent regulatory drivers that create the need for solar air roofing technology are: Executive Order 13423, Executive Order 13514, and Energy Independence and Security Act 2007.

The Energy Independence and Security Act 2007 requires that "each agency shall apply energy conservation measures to, and shall improve the design for the construction of, the Federal buildings of the agency" to achieve a reduction in building energy use by 30% by 2015.

Executive Order 13423 specifically calls for a reduction in energy intensity by 3% each year, leading to 30% by the end of fiscal year (FY) 2015 compared to an FY 2003 baseline. It also requires that agencies ensure that at least half of the statutorily required renewable energy consumed by the agency in a fiscal year comes from new renewable sources, and to the extent feasible, the agency implements renewable energy generation projects on agency property for agency use. Implementing Federal Renewable Energy Requirement Guidance of January 28, 2008 from the Federal Energy Management Program states that solar thermal energy qualifies to meet this Executive Order requirement.

Executive Order 13514 requires agencies to set greenhouse gas emission reductions goals which DOD has set and described in the DOD Strategic Sustainability Performance Plan FY2012. That plan states that DOD will reduce greenhouse emissions by 34% by 2020 using energy efficiency for 37.5% of the reduction and renewable energy including solar thermal energy for 18% reduction in facility electrical use.

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2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

For this demonstration, American Solar installed 9,275 square feet of solar air heating roof over existing built up roofs on the Gaffney Fitness Center, located at Ft. Meade, MD. A simple schematic is shown below in Figure 2. A total of 7,715 square feet were installed over the sloped built up roof above the gym. Another 1,560 square feet of solar roof was installed above a flat built up roof, creating a large mechanical room.

Solar fans were installed to draw air from the roof and deliver it to the outdoor air intake of an air handler and to the air to water heat exchanger and then directly to the gym or to an outdoor exhaust. Cold domestic water was drawn into the system and preheated in the heat exchanger then returned to the domestic hot water boiler for final heating to the required building temperature. Temperature sensors were installed throughout the system to measure solar roof air temperature and delivered air and water temperature to permit calculation of energy delivery and permit calculation of energy cost savings.

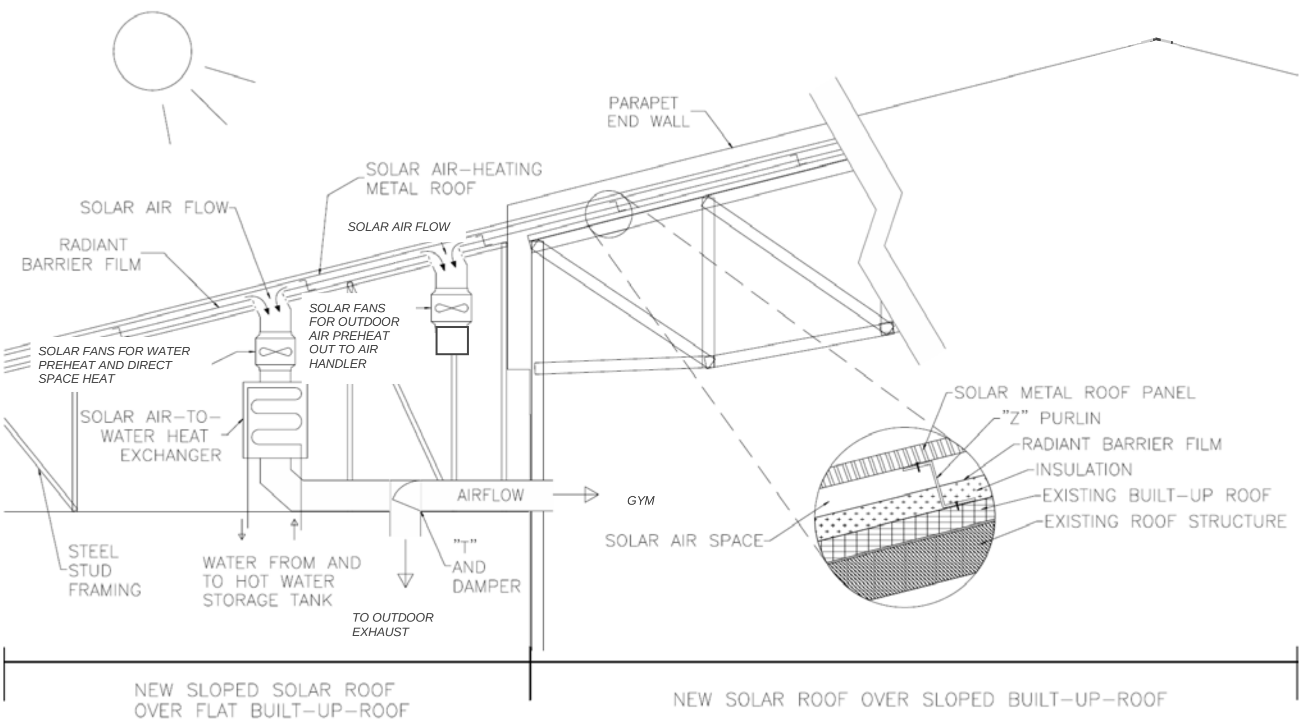


Figure 2 Concept Schematic Section

The basic solar air heating roof concept has been installed in a variety of ways, using roofing materials that are appropriate for a majority of DOD buildings, from aircraft hangars, to commissary and exchange buildings, to DOD schools and family housing, and more. In general, buildings with internal heating needs for space heating, water heating, or industrial process heating are good candidates. Space heating loads, including outdoor air preheat loads are greater, in cold climates. So, the economic advantage of the solar air heating roof will be greater in colder climates. However, even in warm climates, the solar air heat can be used for water heating and other year round heating loads in many DOD buildings.

Because the solar air heating roof serves both a heating need and a roofing need, it can be installed to maximize cost savings for either purpose. However, the best economics result where both heating cost savings and the life cycle roofing cost savings occur. With asphalt and membrane roofs covering a large percentage of the ~500,000 DOD roofs and considering those with reasonable heating loads, a “rough order of magnitude” estimate of 250,000 DOD roofs would be eligible candidates. With asphalt and membrane roofs needing replacement about every 15 years, about 15,000 to 20,000 DOD buildings would be candidates in any given year.

In addition to the Gaffney Fitness Solar Re-roof, American Solar completed another part of a second Solar Roof ESTCP project at the Marine Corps Air Station in Beaufort, SC. That project involved the installation of a radiant barrier film installation below an existing metal roof that had been retrofitted over an original built up roof. The installation and testing was intended to be part of a solar geothermal project under ESTCP contract to Clemson University. The description of that radiant barrier installation and the cooling potential and solar heat recovery potential of that project are covered only in Appendix A-6 of this report

2.2 TECHNOLOGY DEVELOPMENT

Solar air heating metal roofs were first patented in the late 1800s. In the US, there was some commercial development in the 1970s with the onset of the ‘modern day energy crises’. Solar air heating collectors, with glazing covers were developed to deliver high temperature for direct space heating in winter climates, but were generally too expensive to be widely economical and had to be mounted on, and through, the weathertight roof.

In the 1980s an unglazed solar siding systems was developed and patented in Canada and marketed under the trade name Solarwall®. This siding system incorporated many small holes in a metal sheet with a singular corrugated profile. When installed on a sunny wall, outside air was solar heated as it was pulled through the holes and delivered to the building. The product was functional but limited in its application to walls and outdoor air preheat with limited direct space heat. It also required new siding for every application, preferably on a deep, heavy sub-frame standing off of the existing wall. It also provided limited use during the summer with high solar angles, and could not be used as a weathertight roof due to the holes in the panel.

There was little commercial air heating roof development until the late 1980s when 20,000 residential and commercial systems were installed in Japan. These Japanese systems used solar heated air from the roof to flood the crawl spaces of houses to warm the floor, but with relatively low temperatures delivered to the space.

American Solar began to patent, design, and install systems in 1995. American Solar began to install solar air heating roof systems in 2002, and large commercial and government projects with unglazed metal roof systems were installed beginning in 2006. American Solar has installed all the largest solar air heating roofs in North America, which are all on DOD and other government buildings. These largest solar roofs include DOD installations; on an office building, a maintenance shop, a maintenance depot, and now on the Gaffney Fitness Center.

Systems have also been installed on residential and commercial buildings using a variety of metal roofing types. Similar systems using solar air heat recovery from conventional metal walls have also been installed. In several cases, the solar heat has been recovered from existing roofs and walls, with no new roofing or siding required. In other cases, new roofing or siding has been installed to provide the solar air heating surface and to provide the weathertight building envelope. All these systems are the same in that they recover solar heated air from below a metal roof panel (or behind a metal wall panel) and deliver the heated air to the building for a variety of uses.

American Solar has installed systems for the following purposes: outdoor air preheat, direct space heat, water preheat, high temperature (130-160F) water heating, swimming pool heating, combustion air preheat, paint booth air preheat, heat pump preheat, diesel generator standby heating, 'air-radiant' floor heating, high bay heating and de-stratification, dehumidification, and desiccant air conditioning. These systems have been installed on boiler plants, generator buildings, animal barns, office buildings, residential buildings, postal centers, university buildings, and others. Each building has a unique heating system that is sized to the heating demand and heating energy sources (gas boiler, heat pump, electric resistance heat, etc.). American Solar has addressed each building separately with solar roofing, siding, and mechanical equipment that is appropriate for the solar resource and the loads.

To accomplish these past projects over the past 18 years, American Solar's development of the solar air heating roof system has focused on 3 key areas: 1) the solar engineering to predict heat output from conventional, unglazed roofing and siding, 2) prediction of potential building heating loads from internal occupancy (factory, office, etc.), and 3) the application of practical, economical end use applications of the solar heat (outdoor air preheat, pool heating, heat pump preheat, etc.). The integration of the 3 areas has produced several successful installations that have been monitored for short periods and reported in several professional conferences.

This report, on the Gaffney Fitness Center project, provides a sample of the integration of these 3 areas applied to two roofs and three heating loads, with extensive monitoring and reporting of the performance.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY/ METHODOLOGY

The advantage of the solar air heating roof is that it is far more economical than other solar energy systems, providing lower cost heat. This economy comes from making dual use of the roof to serve as a weathertight envelope and a solar heating system.

References 1 and 2 describe two, well known, “single purpose”, “low cost” solar heating systems which are considered to be economical. They describe transpired solar air preheat and polymer solar water heating panels systems. These systems require the installation of proprietary solar panels over the existing weathertight roof or wall and they have installed costs per square foot of $12 (transpired wall) to $42 (water panel). The reported BLCC analysis from these referenced reports shows the transpired wall has a 10 year simple payback period. However, using comparable utility rates for Fort Meade, the simple payback would be 15.5 years. For the water heating panel system, the lowest reported simple payback would be 14 years. In comparison, a solar air heating roof or wall system can be installed (using an existing metal roof or wall) for as little as $6/square foot for fans, ducts & electrical, or $17/square foot, if a new roof is required. With only seasonal use of solar heated air for outdoor air preheat, the simple payback can be as short as 12 years for a building like Gaffney, or shorter if the solar heat is put to other, year round uses (i.e. combustion air preheat). At $17/square foot, the system can deliver solar air heating for seasonal outdoor air preheating, deliver year round water heating, and take credit for the roofing cost savings, resulting in a simple payback less than 10 years.

Because the roof contributes positive savings in the utility bills, it can actually pay for itself over time. All other roofs are considered only an expense. The solar air heating roof is actually an asset that generates cost savings.

The limit of the solar air heating roof is that it can not provide all the heat necessary during all hours of the day. At night, on cloudy days, and during winter days with low sun angles there is reduced or no production of solar heat. So, a backup heating system must be installed that can handle the full heating load and solar heat can provide whatever heating energy is available to reduce conventional heating use by the back up system.

Another limitation is that solar heated air provided by the roof is typically about 20-40F above outdoor air temperatures. This eliminates direct use of solar space heating whenever the solar air is below about 75F. However, outside air preheat can be used no matter how cold the outdoor air temperatures are and cold water preheating can be used, even in January, as long as the solar air temperature is above the incoming cold water temperature. Finally, the limitation brought about by solar air temperature that is colder than the final temperature of the heating load being served, can be overcome by the use of a solar assisted heat pump. The combination of a heat pump to serve a high temperature load and solar heat to improve the performance of the heat pump provides an efficient way to delver warm air or water, year round, in all climates. (Note: Solar assisted heat pumps are not part of this study, but the solar air delivery system from the Gaffney roof system is identical to the solar air system of a solar assisted heat pump. Calculation methods and performance prediction models from this project can support calculations of the performance improvements of solar assisted heat pumps compared to conventional heat pumps.)

A solar air heating roof will often be more socially acceptable than a conventional, add-on, solar hot water panel system as the aesthetics are that of a typical roof. In addition, the long life roof with no penetrations for solar water piping add a level of reliability and reduced risk compared to a solar panel water heating system that is fastened through the weathertight roof.

3.0 SITE/FACILITY DESCRIPTION

3.1 SITE/FACILITY LOCATION, OPERATIONS, AND CONDITIONS

The Gaffney fitness facility includes a gym, which has been converted to an exercise room with various free weights, treadmills, and other exercise equipment. There are men's and women's locker rooms and other activity rooms. The building recently received a major HVAC modification to add air conditioning to the gym and upgrade the HVAC systems in the rest of the building. The heating is by a natural gas boiler that supplies hot water to a coil in the ductwork in the gym. There is a pool that has its own heating and dehumidification systems. The building is generally open from 5 AM to 9 PM.

Figures 3 through 5 show the condition of the Gaffney Fitness Center roof before the re-roof. Shortly after award of the ESTCP contract, the Army Corps of Engineers commenced work under a separate contract to install new air-conditioning systems for the building. This relocated the outside air intakes to the air handler shown on the ground in Figure 4. American Solar revised its design to deliver air to the new air handler.

Figure 3 Gaffney Aerial View

Figure 4 HVAC renovation before ESTCP

Figure 5 Gym roof and wall and flat roof

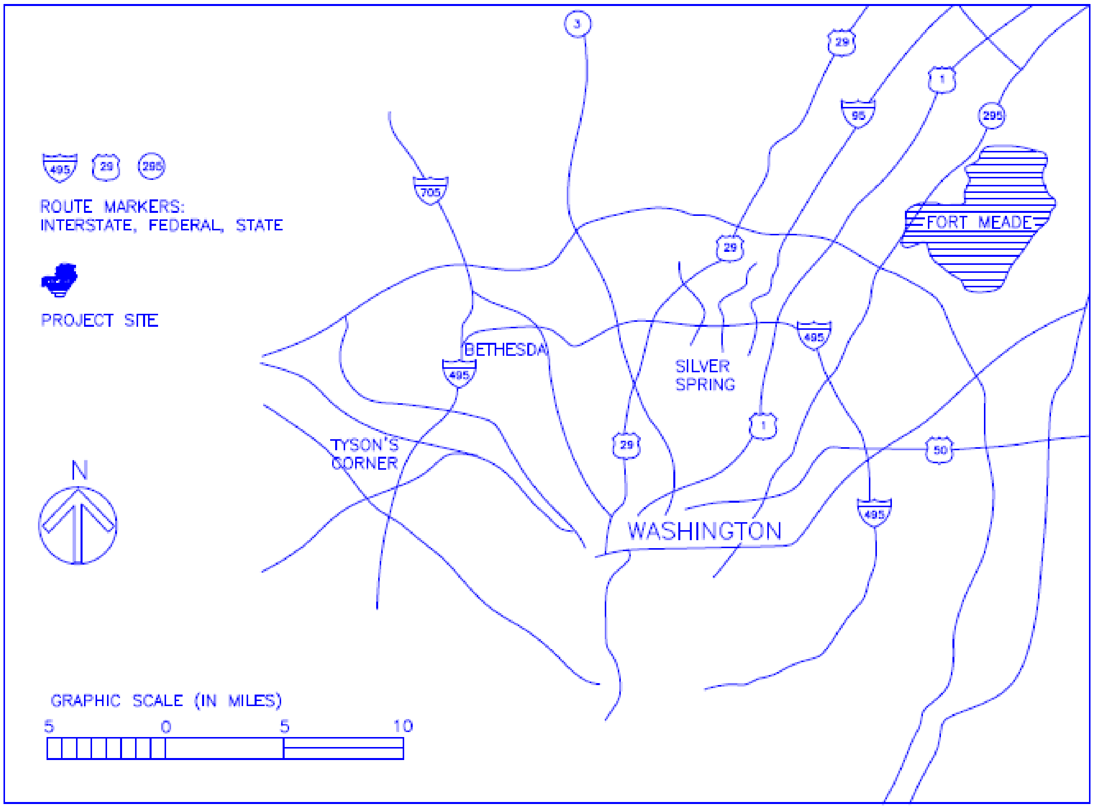


Figure 6 area map

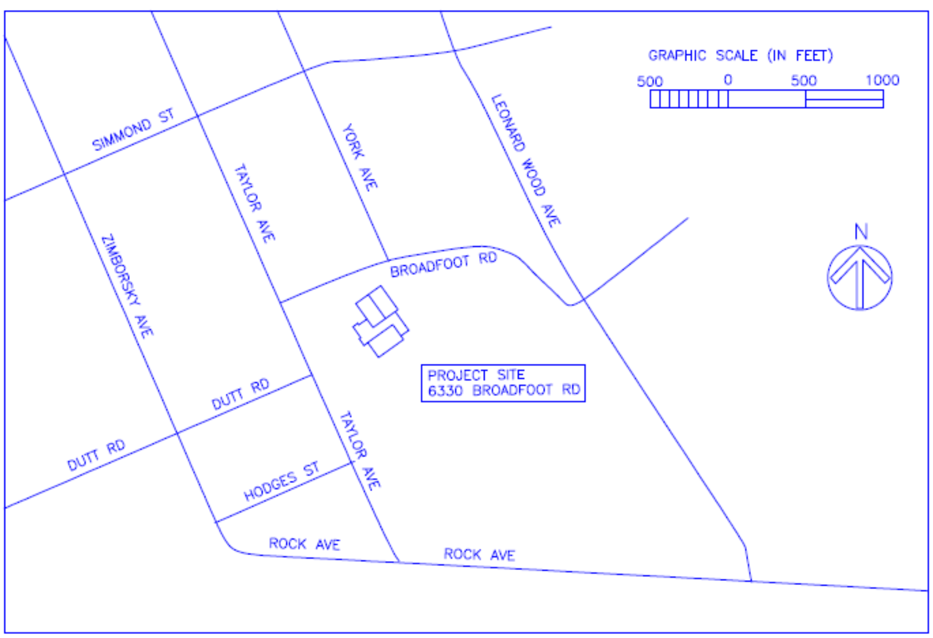


Figure 7 local map

The facility was interested in the solar re-roof both for its roofing value and the opportunity to add a system which would help meet the energy and sustainability goals.

Because the system operates without central control, and there are no programmable features and no communication systems, beyond the acceptance of a simple hard wired relay input indicating a call for heat in the gym, there were no communication issues involving the base central automation system. If the building had no central automated control system, the solar air and water heating system would have simply installed a separate thermostat or relay to indicate to the solar controllers that the gym heating system was ON and solar heat could be provided, when available.

3.2 SITE/FACILITY IMPLEMENTATION CRITERIA

The solar air heating roof can provide solar heating savings in all geographic locations. Any facility with a water heating load can take advantage of the system in any climate zone. However, for outside air preheat, the best advantage is in northern climates, where the facility has a high outside air flow. This might include a laboratory of other building type with high contaminated exhaust air flow through fume hoods, paint booths, or other sources. For direct space heating, mid latitudes will provide a reasonable compromise between high solar temperatures on cool days. In general, a year round low temperature requirement from a single heating load or a combination of heating loads will provide the best economics as the solar heat can be used every day the sun shines.

Buildings with generally unobstructed roofs make the best candidates as the application of the metal roofs panels can proceed efficiently with minimal sealing and flashing around transitions and obstructions. However, existing exhaust fans and vents are easily ducted or extended beyond the new roof surface.

Color is not a particular concern. While black and other dark colors are best from a heat transfer standpoint, other lighter colors have been used and still provide reasonable heat transfer. Often the roof area is large enough that the volume of solar heated air it can generate is larger than is needed to meet the loads. In those cases, a lighter colored roof will still heat up to a reasonably high temperature due to the reduced air flow. In general, to maximize deployment of this energy saving system, initial customer responses have indicated that it is better to provide a weathertight, aesthetically pleasing roof and then recover as much heat as possible, instead of requiring the maximum heating performance from a solar air heating roof that is not socially well received due to color or style.

3.3 SITE-RELATED PERMITS AND REGULATIONS

No permits were required of the re-roof of the Gaffney Fitness Facility. This is typical of most re-roof projects as re-roofing is not considered a major renovation, which invokes new code requirements. However, where a change in electrical, plumbing, or life safety features is required, review by the local authority should be conducted.

Good practice dictates that design documents be developed with a review by the Public Works Department on the base in order to ensure the systems will be operating in accordance with the existing facility operations. This is typically more important for the mechanical and electrical systems (ducts, fans, plumbing, power, and controls). However, for the roofing system; gutters, roof drains, and snow and wind loads should all be considered and documented. Roof type and warranty should also be discussed.

For the Gaffney project, a set of design documents was developed in several stages, (65%, 95%, Released for Construction). Numerous meetings were held with the installation's resource efficiency manager and other personnel to understand the separate HVAC modifications and describe the integration of the solar roof with those modifications and the building.

Roof color was discussed with the Public Works Department and black was selected to maximize solar performance. While black is not a common metal roof color on the installation, there are many different light and dark standing seam roof colors across the installation. So, no particular color standard had been established. If a specific color is required by a particular facility, then the solar heating performance of that color must be calculated in projecting annual energy delivery.

4.0 TEST DESIGN AND ISSUE RESOLUTION

4.1 CONCEPTUAL TEST DESIGN

The solar re-roof system provides heat energy to the building in 3 ways. The system provides solar heated air via fans and ducts:

1. for outdoor air preheat for the gym air handler
2. directly to the gym for space heating and
3. to preheat domestic hot water in an air to water heat exchanger

In addition, the solar roof reduces summer heat gain and winter heat loss through the roof.

The fan based operations are all controlled by differential temperature controllers, which compare temperatures of the solar heated air in the roof to temperatures of the air or water of the load being served. When the solar air is warmer than the load being served, the differential temperature controllers turn the solar fans ON. A connection to the existing building automation system ensures that the solar fans only provide space heat or outdoor air preheat when there is a 'call for heat' in the building. Additional thermostats in the solar controls ensure that the system is protected from freezing by supplying warm air and water to the water filled heat exchanger and piping in the solar mechanical room, which is the area most likely to see freezing temperatures during the coldest weather.

The temperature of the solar heated air or water compared to the existing outdoor air, gym air, or cold water entering the building is an indication of the heat being transferred by solar energy. When that temperature difference is multiplied by the mass flow and the specific heat of the solar air or water the exact quantity of solar heat transferred to the building is determined. Since the solar heating systems directly reduce the existing heating loads, every BTU of solar heat delivered is a BTU of conventional heat not required to be delivered from the conventional heating systems.

The exact temperatures of the solar heated air and water delivered (dependent variables) were measured along with local weather and solar conditions (independent variables) in order to analyze the 7 month performance. System fan and pump ON-OFF data was collected along with the BAS 'call for heat' signal. All this data was used to create a predictive model that can establish solar air and water temperatures, 'call for heat' and solar fan and pump ON-OFF periods. The predictive model can be used to establish solar roof thermal performance for any facility where local solar and weather data are known. The solar roof thermal performance can then be used with available building load temperatures for outdoor air, space heat, 'call for heat', and cold water to predict the hours of solar roof operation and solar heat delivered for any facility.

4.2 BASELINE CHARACTERIZATION

While a review and summation of the annual heating energy bills was conducted, and it does provide a gross baseline for comparison of solar energy delivered, it is not practical to precisely characterize the existing energy use of the Gaffney building for that purpose. This is true of most buildings with heating loads that have varying occupancy and face varying weather conditions from day to day and year to year.

For the solar air heating roof, the best measurement to characterize the system performance is to simply measure the energy delivered when the solar roof system could contribute to a reduction in building energy use. For example, when the building automation system called for heat and the outdoor air preheat fans were running, multiplying the measured temperature difference between the solar heated air and the outdoor air, times the known mass flow of air, times the specific heat of air provides a total heat flow to the outdoor air.

By comparing this value of the heat delivered to the outdoor air against; wind, outdoor air temperature, and solar conditions, we can establish baseline performance of the system against existing weather and solar conditions. This permits the use of the performance model at any location where solar and weather conditions are known. So, total annual solar energy delivery can be predicted for any predictable weather and solar conditions. Beyond the solar performance prediction, the ON-OFF nature of the any building loads being served must also be determined to accurately apply the predicted solar heat. With the predictive solar model and the local ON-OFF building load data, a baseline solar energy delivery can be predicted for any building.

4.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

Schematic diagrams of the 3 fan based systems are shown in Figures 8, showing the outdoor air preheat, direct space heat, and the air to water heat exchanger for the water preheat system. A separate schematic, Figure 9, shows the additional components of the water preheat system in the boiler room.

The solar water preheat system is set up as a parallel loop to the cold water line feeding the boiler. When hot water is drawn from the sinks or showers, the cold water that enters the boiler flows through both the existing cold water line and through the solar preheat system. The cold water flowing into the solar loop is matched by a flow of preheated water flowing back into the cold water inlet of the boiler loop. Thus, a portion of the water entering the boiler is solar preheated.

Within the appendices there are detailed descriptions of the design, installation, operation and testing of each or the 7 technology applications tested as part of this project.

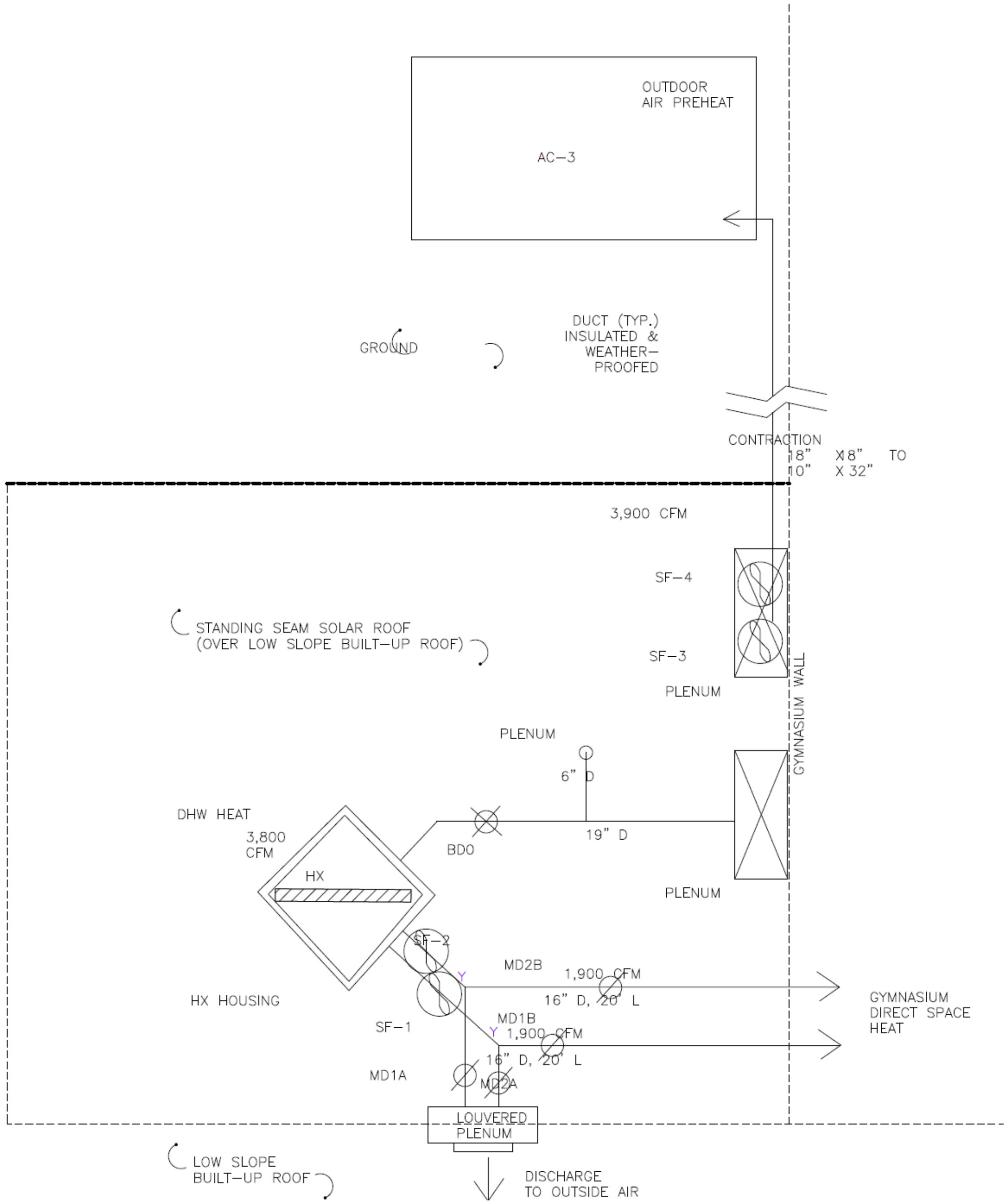


Figure 8 Plan view schematic of solar air mechanical systems

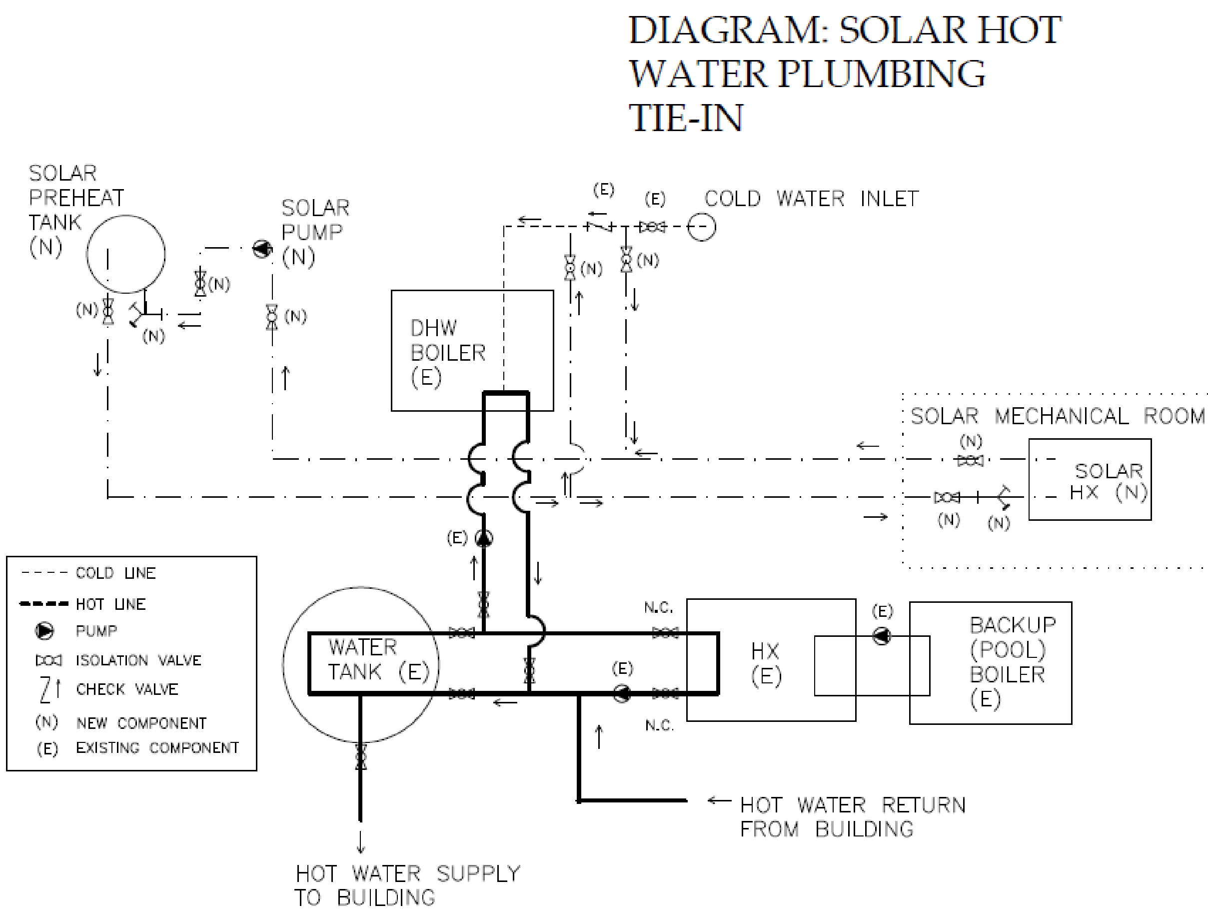


Figure 9 Schematic of water heating mechanical system

4.4 OPERATIONAL TESTING

The construction of the systems started January 2012. In May, the fans were tested to establish the air flow in each duct under various operating conditions. In June, the data logging system was installed and data logging began.

January 2012	Start of Construction
May 2012	Fan air flow testing
June 26, 2012	Start Water preheat data logging, with 2 fans
August 15, 2012	Start Water preheat data logging, with 1 fan
September 12, 2012	End of water preheat data analysis period
October 2012	Start Outdoor air preheat and Direct Space heat data logging
December 2012	End Outdoor air preheat and Direct Space heat data analysis period

Table 1 Operational Testing Schedule

Hot water preheat data logging began June 26, 2012. While data logging continues today, the data from June 26 through September 12, 2012 was used for analysis of the water preheat system. During that period, the water preheat system was set up to run on two fans from 6/26 to 8/15/12 and one fan from 8/15 to 9/12/12.

The change to 1 fan was made after an initial review of the hourly water heating performance showed that there was very little hot water demand from the system during two periods of the day in the late morning and early afternoon. With low hot water demand during these periods, the preheated water temperature leaving the heat exchanger was very close to the solar air temperature, resulting in low heat transfer when this occurred. The electrical energy use of the fans was constant, no matter how much heat transfer was taking place. As a result, a decision was made to operate on only one fan. This reduced the heat transfer from solar heated air to water by about 25% while cutting electrical use of the fans by 50%. Throughout a typical day, it was a more economical arrangement of the system that still delivered substantial heat to the water. As a result the second testing period, with only 1 fan, began in August.

Beginning in early October, the system was connected to the Central Building Automation System and receiving a signal when the gym thermostats called for heat from the boilers. A nearly continuous call for heat began in early November. Testing of the Outdoor Air Preheat and Direct Space Heat systems was conducted during that period. In addition, freeze protection using the pump and a separate fan supplying conditioned gym air to the heat exchanger was validated during that time.

During the operational tests, the system was set to run in fully automatic mode. In general, whenever the solar roof air was warmer than the temperature of the load being served (water preheat, outdoor air preheat, direct space heat), the fans (and pump) turned ON as required. The system was controlled by 3 differential temperature controllers, and by several smaller thermostats used to limit operations to only useful hours. For example, the water preheat fans were prevented from running if the solar air temperature was below 45F, as a safety precaution to prevent cold air from reaching the water filled heat exchanger.

Each system operates using a separate differential thermostat. Outdoor air preheat operates off of one differential thermostat to control fans 3&4. The water preheat operates off a separate differential thermostat to control fans 1&2 and the pump. The direct space heat system operated off a third thermostat controlling both fans 1&2 and the motor dampers.

4.5 SAMPLING PROTOCOL

Data collection was via Labjack data logger system, which collected voltage readings from thermistor temperature sensors as well as open and closed relay contract status for fans, dampers and a ‘call for heat’ from the building automation system.

The data collected from the 10,000 ohm thermistors is a voltage reading. The voltage is converted to a resistance in the thermistor which is representative of the temperature. The voltage readings were written directly to the hard drive of a laptop computer installed in the mechanical room. Over 500,000 individual data points were logged from June 2012 and January 2013.

The voltage readings were then analyzed using an excel spreadsheet. First, the voltage was converted to a resistance value then the resistance was converted to a temperature value.

Conversion of recorded voltage to resistance is:

Thermistor resistance reading (ohms) = 3000*voltage reading/(1-0.4*voltage reading)

Conversion of resistance to temperature is:

Thermistor temperature (F) =
((3890/(LN((resistance)/(10000*EXP(-3890/298.15))))-273.15)*9/5)+32

A one hour sample of the data is shown below, showing temperatures of the thermistor sensors installed in the roof, ducts, outdoors, and on water lines. Relay contacts are the last 4 lines showing the status of the fans and dampers. For example, Fans 1&2 for the air to water heat exchanger switch ON (=0) at 8:59.

The Time	41115.3537	41115.36412	41115.37454	41115.38495	41115.39537
	7/25/12 8:29	7/25/12 8:44	7/25/12 8:59	7/25/12 9:14	7/25/12 9:29
a2f06zone1_hi_air	93.3	95.9	104.1	106.2	108.4
a2f0zone1bur_hi_air	90.6	93.6	100.5	103.1	106.6
a2f1zone1bur_belo_FG	85.3	84.7	85.0	85.1	84.2
a2f2zone1belo_iso	83.9	82.9	84.1	83.8	82.7
a2f3_zone1bur_belo_RB	86.6	88.7	92.8	96.4	99.5
a2f4OAT	82.1	81.5	85.5	86.9	85.7
a2f7fan3and4	85.1	86.1	84.4	85.3	84.9
a5e0h2o_into_hx	76.5	76.2	76.0	80.6	83.5
a5e1h2o_out_hx	76.4	76.2	79.2	82.2	84.7
a5e2solarintohx	75.3	75.4	85.0	87.8	90.7
a5e5returnh2otobldg	76.1	78.0	77.8	82.9	86.4
a5e6solarairoutofhx	73.3	74.0	79.9	84.4	87.7
a5f0zone1_mid	77.0	79.8	81.8	87.0	91.4
a5f1zone1lo	78.9	82.6	91.7	97.0	102.3
a5f2zone1_high	83.5	90.4	93.5	96.4	101.8
a5f3zone1_atticair	72.9	74.3	75.3	75.7	77.0
a5f4zone4lowest	79.6	85.3	88.4	94.4	101.8
a5f5zone4mid	79.2	83.5	85.8	89.0	95.2
a5f6zone4loeast	78.2	80.6	85.3	91.9	97.1
a5f7zone4lhi	84.9	88.3	92.2	94.3	99.8
a5e7coldcityh20	70.2	75.9	70.7	70.1	76.6
c5ci0basgymcallforheat	1.0	1.0	1.0	1.0	1.0
c5ci1mtrdmpr1b2bopentogym	1.0	1.0	1.0	1.0	1.0
c5ci2powertofan3_4atcontactor	1.0	1.0	1.0	1.0	1.0
c5ci3powertofan1_2atcontactor	1.0	1.0	-	-	-

Table 2 Logged Temperature and relay data sample

Local solar and weather data were collected from a USDA weather station within 10 miles of the Gaffney Fitness Center. A sample of the data is shown below.

Time	Air Temp F: Station #4 (−F)	wind speed max mph: Station #4 (mph)	wind speed Avg mph: Station #4 (mph)	wind speed min mph: Station #4 (mph)	SlrW_AVG: Station #4 (W/m2)	RH: Station #4 (%RH)	WindDir_D1_WVT: Station #4 (degrees)	Rain: Station #4 (in)
7/6/12 8:15	85.406	7.19936	4.15072	0.35168	423.8	37.2	53.52	0
7/6/12 8:30	86.144	6.97984	4.4576	1.12	449.5	34.89	63.17	0
7/6/12 8:45	87.026	8.34176	5.30432	2.02048	491.6	37.57	97.3	0
7/6/12 9:00	87.62	6.43104	3.69376	1.0752	529.8	34.05	59.93	0
7/6/12 9:15	88.232	8.51648	4.9728	0.39424	565.8	33.51	75.1	0
7/6/12 9:30	88.97	7.85792	4.58304	0.68096	454.9	32.91	126.9	0
7/6/12 9:45	88.88	10.77888	4.21568	0.0224	617.4	33.68	66.53	0

Table 3 Local weather and solar data from USDA site

A sample calculation of heat transfer is provided here for the water preheat system along with a description of the calculation for the outdoor air preheat and reduced heat loss/gain through the roof. Detailed discussions are provided in several appendices written as stand alone white papers.

Water Preheat

On July 6, 2012, the heat transfer from the solar heated air to the water can be calculated using the temperature difference of the solar heated air into and out of the heat exchanger, the mass flow of air and the specific heat of air.

The formula for the heat transfer is $\dot{Q} = Cp \times \dot{m} \times dT$

Where
$\dot{Q}$ is the heat transfer in BTU/hr
Cp is the specific heat of air = 0.24 BTU/#dryair/DegF.
$\dot{m}$ is the mass flow in #dryair/hr = 3320 cfm x 60 min/hr / 14.6cuft/#dryair = 13,644#dryair/hr
dT is the temperature drop in air across the heat exchanger = 13.4F at 11:59 , and average 6.7F for all ON fan hours

For example, at 11:59 the temperature difference is 13.4 F so the heat transfer is:

$\dot{Q}$ =0.24 x $\dot{m}$ x dT = 0.24 x 13,644 x 13.4 = 43,800 BTU/hr.

Heat transfer from the air is, for all practical measurement purposes, essentially equal to heat transfer to the water.

A regression analysis was performed using solar, wind, and outdoor air temperature to predict the solar roof air temperature. An analysis was also performed to predict the temperature difference between Outdoor Air and Solar Heated Air when the solar fans are turned ON and OFF. A final regression analysis was performed to predict water temperature into the heat exchanger based on solar and weather conditions. Together, these calculated values, for the first time, permit the calculation of solar air heating roof performance at preheating water over any multiday period, using Typical Meteorological Year (TMY) data and solar data.

A sample of the prediction of the model is shown in Figure 10 for the cases where 1 fan and 2 fans are used to move heat through the heat exchanger during several July days.

With the model in place, a calculation of all hours of the year can be made to calculate the ON –OFF times and the temperature difference and heat transfer in the air to water heat exchanger. The sum of the hourly heat transfers gives the monthly and annual heat transfer. Dividing by the 90% efficiency of the boiler gives the total natural gas heat saved in the boiler by the solar water preheat system. A review of the hourly data gives the peak hourly and monthly heat transfer.

A second analysis with the model uses 100% cold water entering the heat exchanger. This is the "maximum savings" case. This case simply uses only cold water in the heat exchanger to improve heat transfer and maximize savings. The analysis is the same and it generates monthly and annual savings.

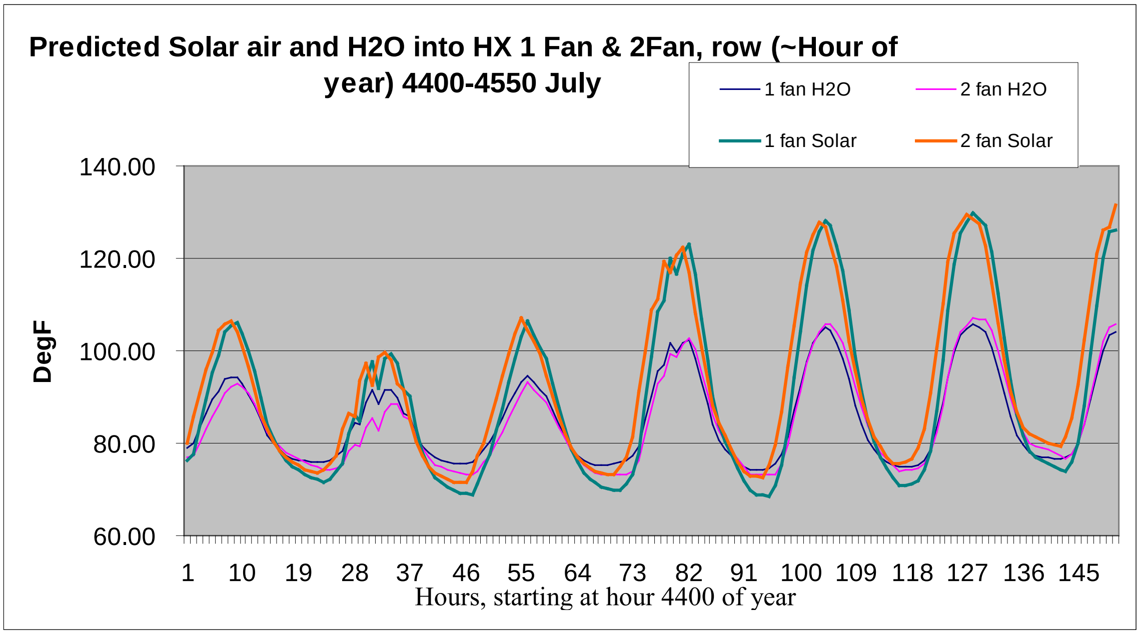


Figure 10 Predicted solar and water temperature

Outdoor air preheat and Direct space heat

A similar set of analyses were performed to predict the solar roof temperature and fan ON-OFF times for the Outdoor air preheat and direct space heat cases using TMY data. Results of the model to predict solar air temperature are shown in Figure 11. Using

1. the predicted air temperature
2. the temperature difference between the solar air and outdoor air
3. fan ON-OFF times and
4. air mass flow,

the heat delivered to the outdoor air can be calculated.

The calculation for 'direct space heat' of the gym is similar to the calculation of 'outdoor air preheat' of the air handler, with the exception of using a temperature difference between solar air and the desired solar supply air temperature to the gym of 78F, i.e. (temperature difference = solar air –78F). The 78F temperature is 8F degrees warmer than the normal 70F gym air and the minimum temperature to supply solar heated air for direct space heat of the gym. This minimum temperature difference of 8F above the normal gym temperature ensures that the cost savings of the solar heat delivered is more than enough to overcome the expense of running the fans.

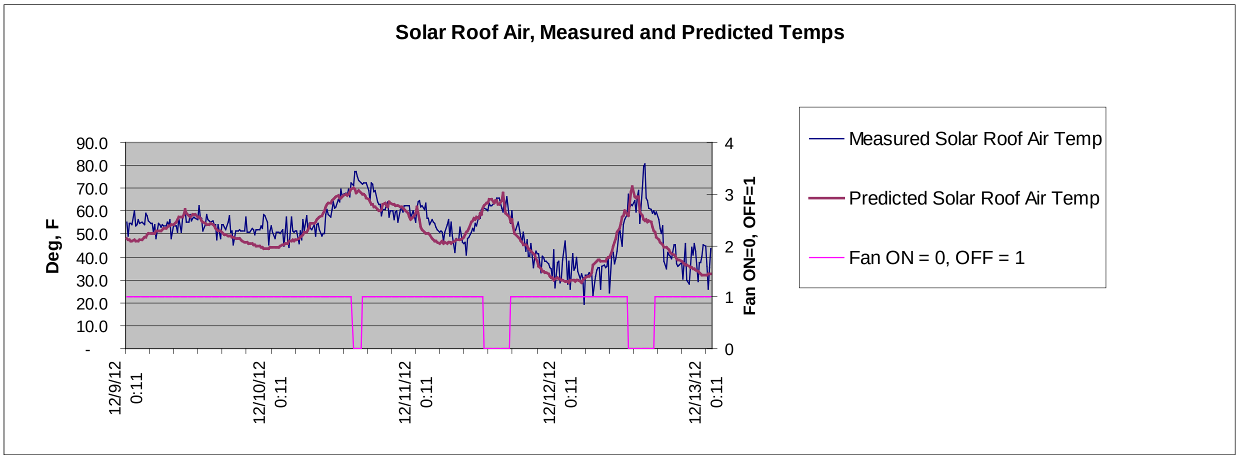


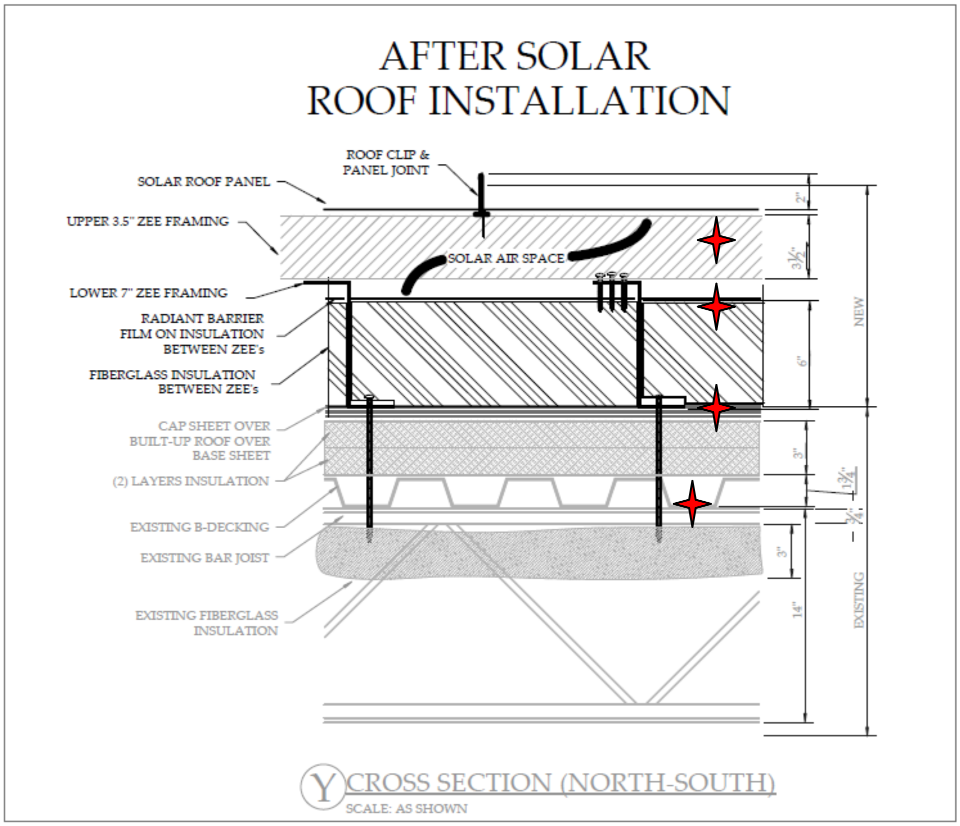
Figure 11 Predicted solar temperature and fan ON OFF

<u>Reduced roof heat loss in winter and heat gain in summer</u>

One set of thermistor sensors were placed in the roof in a vertical stack, Figure 12. (See Appendix A-3 for a complete discussion of this topic and photos and drawings of the sensor arrangements.) The upper sensor in the vertical stack was in the solar air space, another sensor was 9 inches below it was on top of the old built up roof. The sensor on the old built up roof measured the temperature of the old built up roof surface that was covered by the solar roof.

A separate set of temperature readings of the surface of the nearby exposed built up roof was taken on sunny days. These surface temperature readings were taken by a handheld infrared thermometer. The surface temperature readings permit a comparison to be made between the temperature of an exposed, non-solar built up roof to the covered built up roof under the solar roof, to evaluate the insulating effect of a solar roof. Figures 13 and 14 show the temperatures of the outdoor air, and the old built up roof during a winter and a summer day.

During the heating season, from the late afternoon, through the night, to mid morning, the temperature of the exposed, non-solar built up roof would be at or near the outdoor air temperature, while the covered BUR stays warmer under the solar roof. During those hours, there is reduced heat loss through the covered BUR under the solar roof compared to the heat loss roof through the colder, exposed, non-solar built up roof. By calculating the temperature difference between covered and exposed roofs, and knowing the R value of the roof from the BUR to the interior gym ceiling, we can calculate the heat loss avoided in winter.



Roof Temperature Sensor locations in a vertical stack:

1) In solar air space,
2) Below radiant barrier,
3) Below fiberglass (on top of old Built Up Roof, and
4) on top of roof deck

Figure 12 Roof Sensor Location, vertical stack

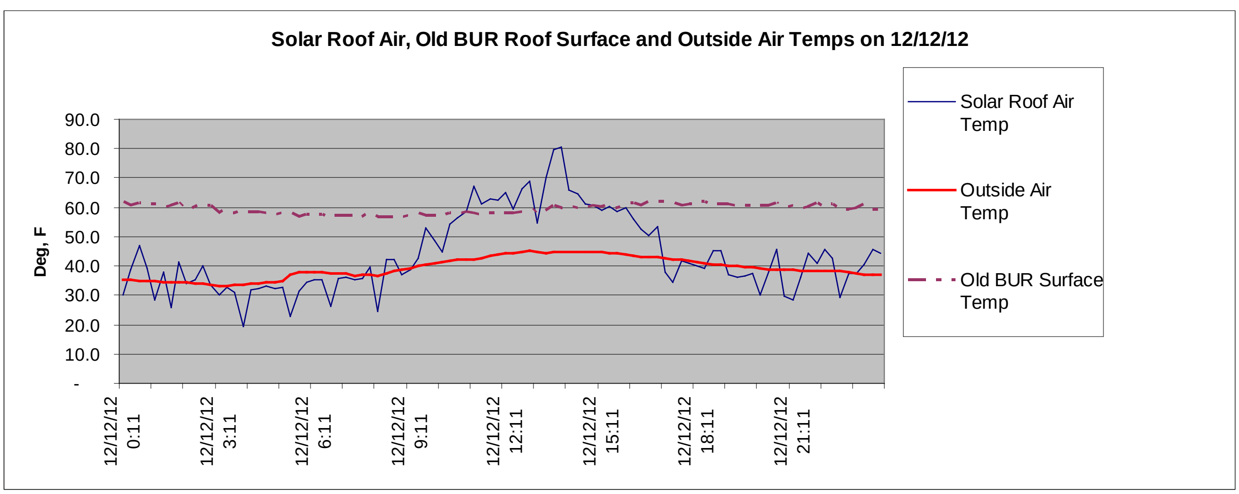


Figure 13 Solar, Old Roof and Outside Air Temperatures

A similar analysis was conducted for summer heat gain as part of an ESTCP request to compare the roof to a reflective "cool roof". This data sampling for this analysis sought answers to 2 questions: 1) "What is the effect of the solar roof on summer heat gain through the existing roof?", and 2) "How does the solar roof heat gain compare to a "cool roof?". It also involved extracting data from other, prior roof tests conducted at Oak Ridge National Laboratory.

The testing showed that the added insulation of the solar roof, including the use of a radiant barrier actually keeps the covered BUR under the solar roof cooler than the adjacent, exposed, non-solar BUR, during peak summer cooling hours. The following graph shows data for the solar covered BUR compared to the non-solar, exposed BUR. At 11:59AM, the non-solar BUR (Oval #1) is 70 degrees F hotter than the solar covered BUR (line a2f2zone1belo-FG). Other temperature readings, taken with an infrared spot thermometer during several mid-day surveys, of the exposed, non-solar BUR showed consistently high, mid-day surface temperatures on the exposed, non-solar built up roof. Additional published results of past tests of several roofs conducted at Oak Ridge National Laboratory, show similar high roof surface temperatures for conventional, exposed roofs.

By sampling and comparing the data point from the mid-day, spot testing of the exposed roof at the Gaffney Fitness Center to the daily Oak Ridge test data, an hourly estimate of the exposed, non-solar BUR temperature can be made. Using the hourly estimate of the exposed, non-solar BUR temperature and the roof 'R' value from the BUR to the interior ceiling, provides an hourly heat gain for the exposed, non-solar roof. A similar calculation is provided for the covered BUR below the solar roof. The difference between the solar and non-solar roofs is the heat gain avoided by the solar roof.

This avoided heat gain causes a reduction in the air conditioning electrical energy use. That reduction is most pronounced during the peak mid-day hours when electric rates are highest. At 11:59AM, the heat gain to the gym under the solar roof is 14,263 BTU/hr less than the heat gains from the exposed, non-solar built up roof. This is the equal to reducing the air conditioning demand by 1.2 tons during that one hour.

So, the answer to question 1 above is that. "The solar roof actually cuts the summer heat load on a building, saving electricity in cooling during the peak cooling hours."

To compare the solar roof to a "cool roof" two techniques were used involving the sampled data. The first uses the temperature data from the solar roof and compares it to, temperatures from a 'cool roof' tested at Oak Ridge National Lab. This comparison indicates that the solar roof reduces summer heat gain by an amount comparable to a 'cool roof'. See Figure 15 below, which shows the addition of the Oak Ridge 'cool roof' temperatures (ORNL white membrane) to the temperatures of the built up roof below the solar roof (line a2f2zone1belo-FG).

The comparison to the Oak Ridge cool roof test shows temperature of the solar covered BUR averages 6F cooler than the Oak Ridge Cool Roof during the hours with peak electricity rates, reducing the cost of both electricity consumption and demand. During the less expensive off-peak rate hours, the sampled data shows the cool roof averages between 22F and 28F cooler that the BUR under the solar roof. By this estimating method, the 'cool roof' saves slightly more ($20/year) than the solar roof.

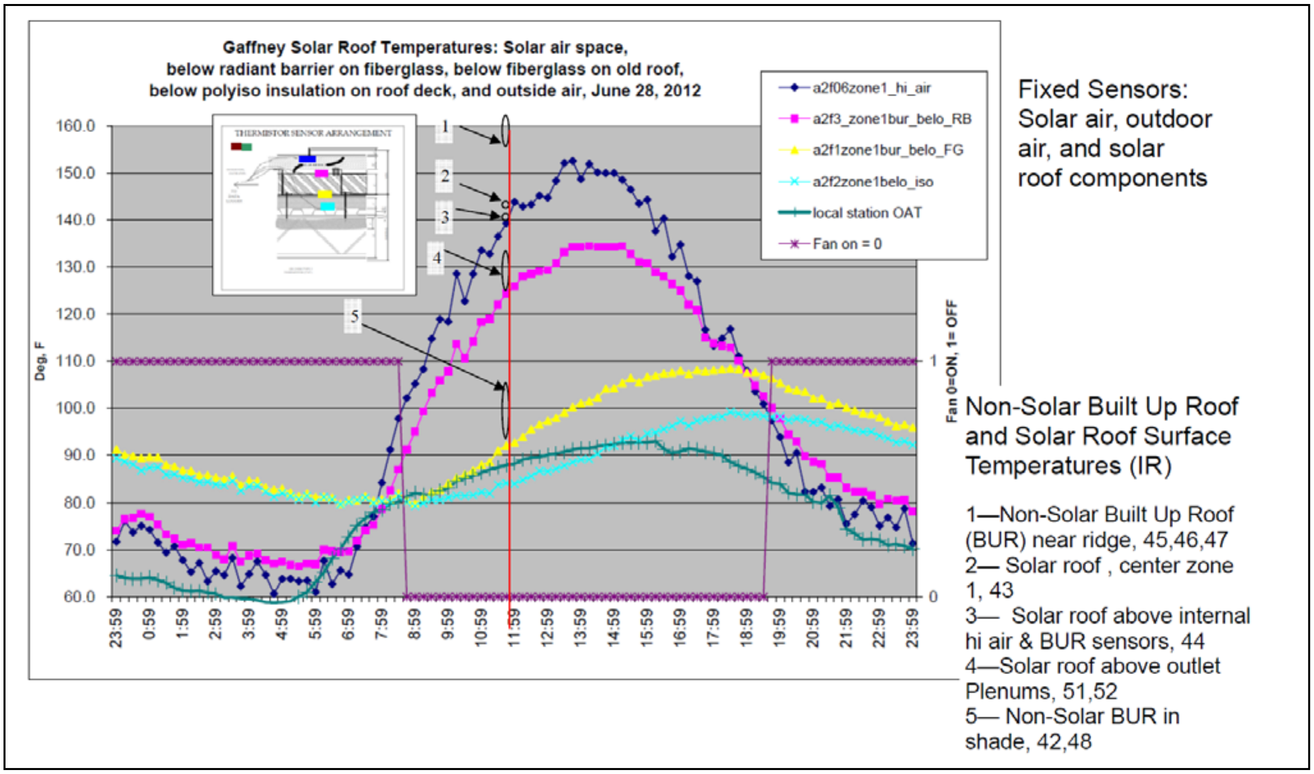


Figure 14 Solar Roof Temperatures Vertical Slice

A second method of testing the summer heat gain impacts involved 1) estimating the solar roof heat gain savings vs. the existing exposed BUR and 2) estimating an 85% reflective "cool roof" savings vs. the existing exposed built up roof. The Solar roof vs. the existing BUR was calculated by conservatively modeling the hourly temperature of the existing BUR temperature as the same as the sampled hourly temperature of the solar air space. The difference in the temperatures and the R value from the BUR down to the gym ceiling are used to calculate the heat gain. With this calculation, the solar roof saves $83/year in electricity consumption and demand charges compared to the existing built up roof.

To estimate the impact of the 85% reflective roof vs. the existing exposed BUR, the Cool Calc Peak computer program was used with an estimated reflectivity for the existing BUR of 50%. The program projects that the 85% reflective roof will save $69/year in summer cooling cost compared to the existing exposed BUR. Combining these 2 results would indicate that the solar roof will save $14/ year ($14=$83-$69) compared to the cool roof.

In summary, one calculation method projects $20/year in favor of the cool roof and one calculation projects $14/year in favor of the solar roof. Since the roof is 9,915 square feet, the value per square foot is +/- $0.002 per square foot per year.

So, the answer to question #2 above is: "The solar roof is equivalent to the cool roof within practical, measureable terms."

See Appendix A3 for a comprehensive discussion of the sampling and comparison using the 3 techniques to compare the solar roof effects to a “cool roof”.

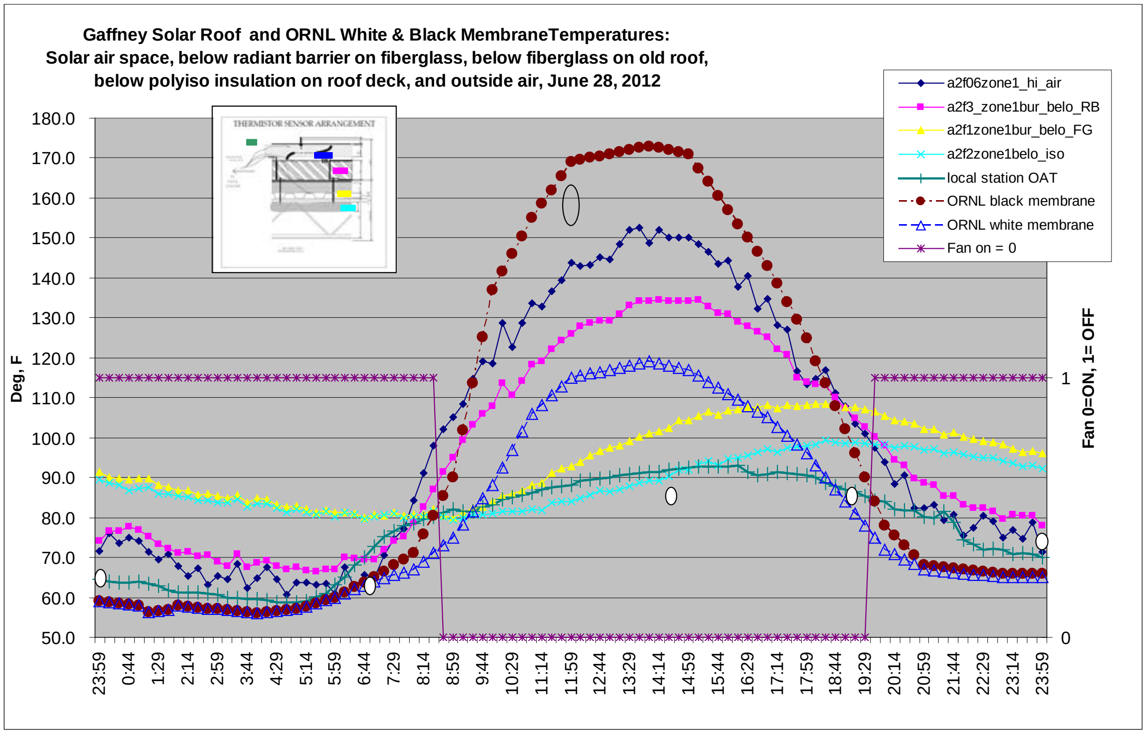


Figure 15 Gaffney and Oak Ridge 'Cool Roof' Temperatures

4.6 EQUIPMENT CALIBRATION AND DATA QUALITY ISSUES

The principal analytical testing equipment was the thermistor sensors, Labjack data logger, Pitot Tube, and Manometer

Thermistors have a +/-1% accuracy.

The voltage for the thermistors is from 5 volt DC sources from the Labjack, passed though a voltage divider circuit using 1% and 5% resistors. At several locations there are multiple thermistors installed and measuring the same temperature to provide additional validation of the measurements. In addition, local temperature readings with dial thermometers, infrared thermometers, and thermistors connected to portable data loggers were used to spot check the temperatures.

During commissioning of the solar fans, air flow readings were taken of each duct using a pitot tube and hand held digital manometer. The pitot tube has an accuracy of +/-2%. The manometer has an accuracy of +/-0.3%. ,

In addition to the data logged on the site, weather and solar data were downloaded from a nearby USDA site. The site was about 10 miles from the Gaffney building. If data were being collected for a single day or for a few days, the distance would be of concern as local clouds cover and weather conditions could cause a variation in solar and temperature readings. However, with the high number of readings, ~21,000 readings at 15 minute intervals, any differences are likely a small percentage of the whole data set.

During the data logging, only two anomalous readings were noted, these readings were discovered when the voltage readings peaked to a full scale reading and departed from other roof temperature readings by 10-15F. The readings were discovered during regular downloading of the data. In one case, the thermistor sensor was disconnected from the Labjack contact terminal and reconnected to another terminal. In the other case, the sensors was disconnected and reconnected to solve the problem. The data from those periods was not used in performing the regression analyses.

There are 5 appendices which describe the detailed analysis of the data for each of the different elements of the Demonstration. These include: Water Heating, Outdoor Air Preheating and Direct Space Heating, Solar Roof vs. Cool Roof, Radiant Barrier Performance in Solar roofing, and Life Cycle Cost Analysis. Each of these is written as a stand alone White Paper describing the testing and detailed analysis from the Gaffney project.

4.7 SAMPLING RESULTS

A sample of the water preheating system results are shown in the graphs, Figures 16 & 17 below. They show the temperatures of the solar air in the roof and entering and leaving the heat exchanger, the cold city water entering the solar preheat system, the water temperature into and out of the heat exchanger and returning to the building, and the fan ON-OFF status.

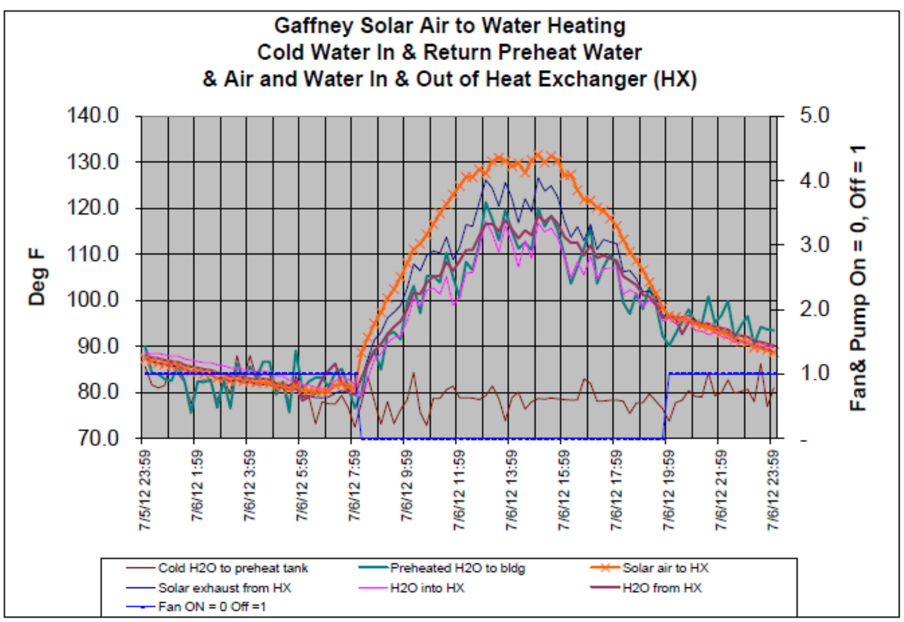


Figure 16 Air to water heat exchanger temperatures

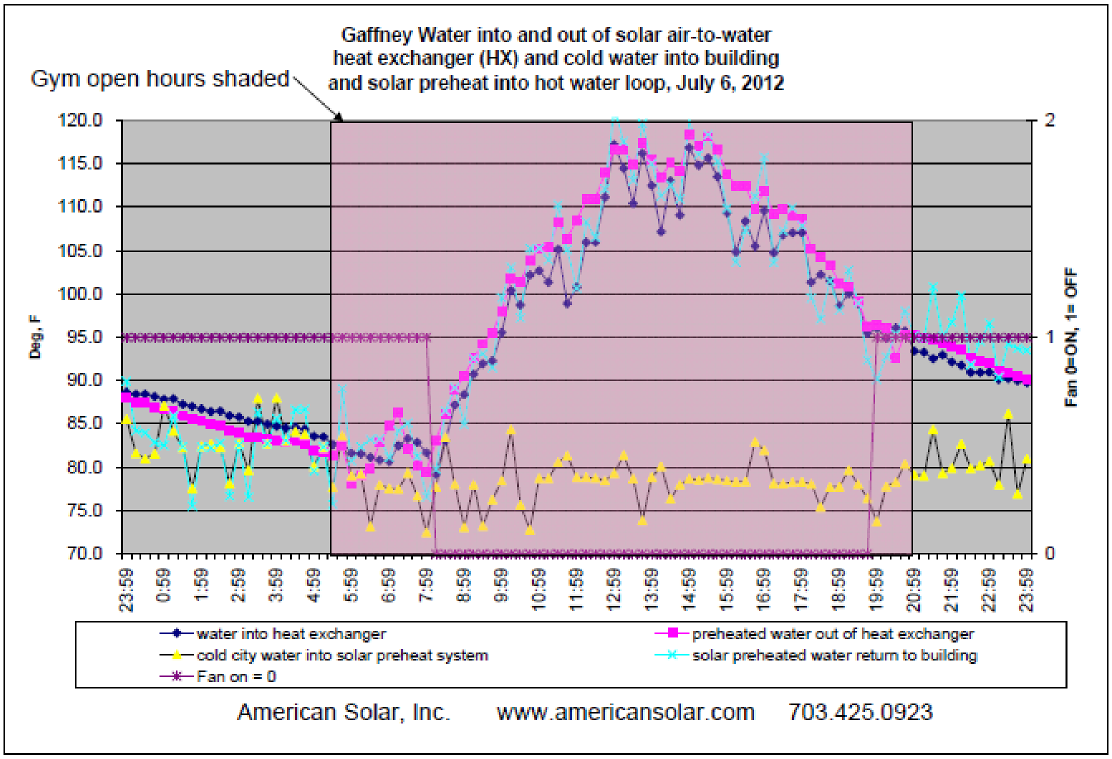


Figure 17 Water heating & gym hours

A sample of the data collected for the Outdoor Air Preheat is shown in Figure 18.

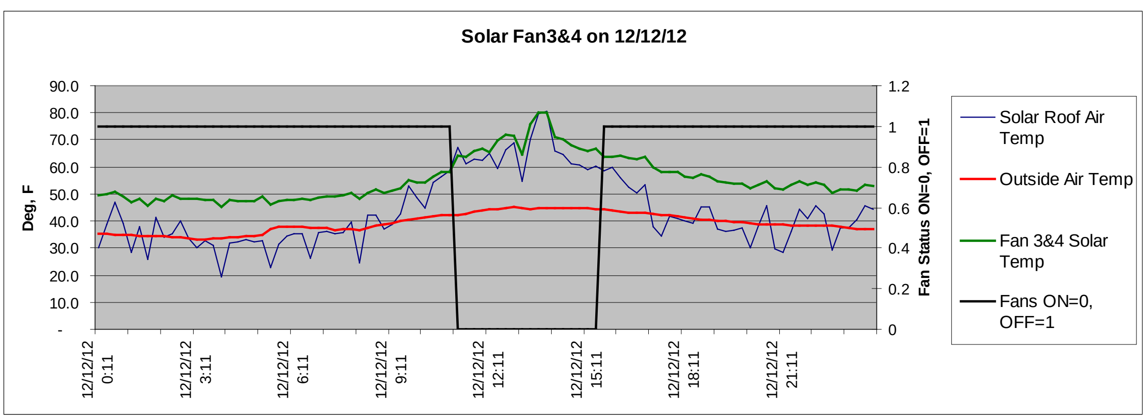


Figure 1 Solar and Fan 3&4 Temperatures

5.0 PERFORMANCE RESULTS

5.1 SUMMARY OF PERFORMANCE OBJECTIVES AND OUTCOMES

The Table 4 & 5 below includes a column for Results of the performance testing and modeling. For each performance Objective, two values are provided. The lower value represents the 'as installed' and operated case. The higher value represents the "maximum savings" case. The difference is discussed after the tables.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Solar energy delivery to air (Energy)	Million BTU of renewable energy delivered to heat the building	Temperature and flow of solar air	Peak heat transfer to air, 50 Btu/sqft/hr Peak Daily heat flow, 300 BTU/sqft/day Peak monthly heat flow, 4,500 Btu/sqft/winter mo	Peak 47-60 Btu/sqft/hr Peak Daily heat flow, 318-350 BTU/sqft/day Peak monthly heat flow, 3,903-4,727 Btu/sqft/winter mo
Solar energy delivery to water (Energy)	Million BTU of energy delivered to the domestic hot water	Temperature and flow of solar air, and air to water heating	Peak heat transfer to water, 20 Btu/sqft/hr Average 2,000 BTU/sqft/month April to October	Peak 13.9-64 Btu/sqft/hr Average 1,405-5,851 BTU/sqft/month April to October
Renewable Energy Use	% of Energy Use By Gaffney Gym	Monthly Solar Energy Delivered and Monthly Energy Billing Use from Utility Bills	7% of Building Heat Energy Use (Combination Gas and Electric Heat)	10- 19% of Building Heat Energy Use
System Economics	Roof Cost Savings $ Energy Cost Savings $, Years	Dollar costs, discount rate, usable life, Energy Cost Savings	5% Reduction in life cycle roof costs, 7% Reduction in life cycle heating energy expenses	(31% [increase]) - 25% reduction in roof cost (See Sect. 5.2), 8-20% reduction in heating costs
Direct Greenhouse Emissions	Direct fossil fuel GHG emissions (metric tons)	Measured or estimated release of GHG based on source of energy	7% Reduction compared to baseline heating energy greenhouse emissions	5-15% Reduction vs. baseline heating energy greenhouse emissions

Table 4 Quantitative Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Demonstrated
Qualitative Performance Objectives				
System maintenance	Consolidate all component maintenance and operations requirements Report on overall solar re-roof Design/Build opportunities, processes, procurement approaches Report on Roof Maintenance cycle	Maintenance and operating instructions for each component Document steps taken to Assess, Design, and Build a solar metal air-heating re-roof Years to repair or replace roof	Operation and Maintenance Guide (Facilities) Design Build Guide (Facilities) 30 year solar roof repaint 40 year solar roof life	O&M Guide Complete Design Build Guide Complete Roof Maintenance Cycle Report complete
System Reliability	Percent Time System performs as designed	Run Time / Downtime hours	5% Downtime Hours 95% Run time Hour	2% downtime hours 98% runtime hours

Table 5 Qualitative Performance Objectives

5.2 PERFORMANCE RESULTS DISCUSSION

The Quantitative Objectives

The evaluation of the performance of the solar roof was done in two ways, 1) "as installed" and operated, and 2) by calculating the "maximum savings" performance of the system using the developed analytical model. The "as installed" and operated savings values in Table 4 account for the installed cost of the systems and the way they were operated to deliver the most information during the testing period. The "maximum savings" case accounts for the best life cycle cost installation and operations.

As an example from Table 4, in the System Economics category, the 31 % increase in roof cost refers to the "as installed" case and the 25% decrease refers to the "maximum savings" case. The difference is a result of the unique construction of the "as installed" system at the Gaffney Fitness Center, which was designed to gather cost and performance data on two types of roof construction and two operating profiles.

The “as installed” roof system is economical and provides positive roofing and energy cost savings. However, both the installed system and the testing operations were deliberately configured in a manner that focused on providing the most information on the cost and performance of the system and less on optimizing to the lowest life cycle cost installation. As a result, important cost and performance data was collected to support a broader set of future designs and installations.

Specifically, the system was built with two types of roofing structure and operated with single and multiple fans. This enabled collection of installed cost of two types of roof construction and energy savings information on two modes of operation. Had the system been designed just to minimize life cycle cost, then one type of solar roof would have been installed, over only the smaller sloped gym roof, and only a smaller, one-fan system for water preheat would have been installed.

The ‘as installed’ system incorporated all costs of the installation divided by the total square feet of solar roof. The portion of the solar roof installed over the flat BUR, provided valuable data on the heating performance of that section, but it added significant cost to the solar roof ($74/sqft). In contrast, the portion of the solar roof over the sloped BUR above the gym was much less expensive ($20/sqft). As a result, the average cost of the total installed solar roof was $37/sqft. Had the solar roof been built over a comparable area of only the sloped built up roof of the gym, the installed cost would have been much lower, and the life cycle cost savings per square foot been much higher. We report this as part of the values considered in the “maximum savings” case, with a 25% reduction in roof cost.

In operation, the solar hot water heating system was run at all hours that it could save natural gas, even if those hours resulted in lower gas cost savings than the electric expenses to run the fan and pump. This enabled the collection of data that identified the key operating parameters (ON-OFF temperatures, Delta-T water, etc.) that were important to developing the performance model.

Once the performance model was established, the prediction of annual energy and cost savings was possible. This model also enabled the refinement of operating parameters such as ON-OFF temperatures for fans and increased cold water input to increase heat transfer in the heat exchanger. For example, with the electric and gas rates at the Gaffney Fitness Facility, the optimal Turn ON-OFF temperature differential between Solar Air and Outdoor Air is 8.1F in Outdoor Air Preheat Mode. Both of these changes in modeled operations result in higher predicted annual energy and cost savings that are referred to in the reports as the ‘maximum savings’ case.

The Qualitative Objectives

The qualitative objectives provide an Operations and Maintenance Guide for the system at Fort Meade and a Design Build Guide to educate other facility managers on the benefits and considerations of installing solar air heating metal roofs.

An O&M guide was prepared for the Fort Meade maintenance staff as part of a turnover package for the Department of Public Works.
A design Build Guide was prepared for use by other facility mangers considering the use of a solar air heating re-roof.

A roof maintenance cycle report was prepared and incorporated in the O&M report for Fort Meade.

The System operated for 98% of all hours and had only 1 downtime incident caused by intermittent operation of one of the fans. A switch over to a second fan enabled the system to continue operation.

6.0 COST ASSESSMENT

When estimating the cost of the solar roof compared to a conventional built up roof, two key parameters are necessary, first cost and useful life cycle. A built up roof or membrane roof has a useful life cycle of about 15-17 years A solar air heating roof has a useful life cycle of 40 years. So, a solar air heating metal roof will last as long as 2.7 Built Up Roofs. At the end of the life of each built-up roof, the reroof is either re-covered or the old roof is torn off and a new roof is installed.

When the built up roof is installed there is no energy benefit to the building. It is simply an expense to keep the weather out of the building. When a solar metal roof is installed, there is a measureable cost savings due to the solar heat supplied to the building, which reduces energy costs from natural gas, fuel oil, propane, or electric heating sources.

The table below shows the typical costs and savings for a solar air heating metal roof that is installed over a sloped built up roof.

Cost Model for a Solar Air Heating Metal Re-roof

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Hardware capital costs	Solar roof over sloped BUR Fans Duct & Electrical Plumbing Roof Trim & Tie In to BUR Note: Higher cost if slope build up system is required. Lower cost if over metal roof.	$18/sqft $4/sqft $3/sqft $1/Sqft
Installation costs	Labor and material required to install	$5/sqft
Consumables	Estimates based on rate of consumable use during the field demonstration	$0/sqft
Facility operational costs	Reduction in energy required vs. baseline data	Net $0.46/sqft/yr (heat-electricity)
Maintenance	Repaint roof, replace fans at 25 years, $11,316 Replace tank and pump at 10 years, $500	$0.04/sqft/yr
Hardware lifetime	Estimate based on components degradation during demonstration	40 year roof 25 year fans 10 year tank and pump
Operator training	Estimate of training costs	$0.05/sqft/yr

Table 6 Cost Model for Solar Air Roof

[1] Detailed list of materials and analytical costs provided in Final Report

6.2 COST DRIVERS

There are 5 cost drivers to consider when selecting this technology:

1. Roofing need
2. Building heating loads
3. Building structural support of the roof
4. Energy rates for heating vs. electricity and
5. Roof configuration

Roofing need – An installation with a building that needs its roof replaced will be poised to spend about 75% of the cost of a solar roof just to get the roof replaced. So, 75% of the "first cost" of the solar roof is covered just from the avoided roofing expense of a non-solar roof. Over its long life, the solar air heating metal roof will actually save more money in roofing cost than the installation of a series of built up or membrane roofs. Obviously, if the roof is new and does not need replacement for 10+ years, the immediate cost savings will be less, but the solar roof is still likely to save more over time than a series of membrane or BUR roofs.

Building Heating loads – A building that has a high heating load can make maximum use of all the solar heating capacity of the solar air heating roof. This includes year round heating loads or combinations of seasonal loads. For example, a high outdoor air load that might be found in a laboratory or other building where high air flows are required to maintain air quality, will have a high winter heating load in most mid latitude and northern climates. A high water heating load for building heating or domestic hot water loop can be served by the solar air heating roof either as demonstrated at Gaffney or when combined with a solar assisted air to water heat pump. Annual heating loads larger than 40,000 BTU/sqft of roof tend to make good candidates.

In addition, a building with a high temperature heating load, e.g. above 140F, may not have many hours when the solar heated air will be hot enough to contribute heating energy. Often there are other low temperature inputs to a high temperature process that solar can heat. In other cases, a solar assisted high temperature air to water heat pump can be used to convert the low cost solar heat to high temperature hot water at much lower cost that a heat pump alone or other heating source.

For example, if a building has a hot water heating loop for space heating that is designed to constantly circulate water at 130F, then solar heated water delivered below that temperature will be of no value in supplying heat to the loop. In that case, an air-to-water heat pump can take in solar heated air at +/-100F and efficiently deliver 130F water to the loop. Because the heat pump operates very efficiently at the high solar air temperature, the heat delivered to the water requires very little electricity use for the solar fans and heat pump compressors. Typically one unit of electrical energy delivers 3-6 units of heat to the water. This makes the solar assisted heat pump far more economical than using electric resistance heat, or oil or propane fired heat for water heating and more economical than using gas boilers in many cases. While it was not a subject of the

Gaffney Fitness Center test, solar assisted heat pumps have been successfully installed at other federal and non-federal installations.

Building structural support – The solar air heating roof can add about 3 pounds per square foot to the roof. Normally, this is not a concern as a structural analysis will confirm that the roof structure is adequate to support the load. In some case, added structure is required to build up the slope of the roof to tie in different sections or get above obstructions on the roof. In those cases, the added structural cost can be an important economic consideration. For large roofs over 10,000 square feet, the added cost of slope build up systems can be minimal. For smaller roofs, the cost of the added structure can make the roof uneconomical.

Energy rates for heating and electricity – Solar air heating roofs use electric power to run fans and pumps. Normally, the cost of this power is less than 20% of the savings from the heating fuel use. However, heating energy saved for any operating hour must be balanced against the electrical cost for that hour. For each set of electric and heating fuel rates, a balance can be set to ensure that the solar fans and pumps only run when there is a positive net cost savings.

Roof configuration

It is not necessary to install a solar air heating metal roof at an optimum tilt or azimuth angle. In many cases, the roof surface is so large and it delivers so much heat, a less than optimum orientation will still provide more heat to many loads than is required. It is typically more economical to keep the cost of the roof low than to try to maximize the solar heat by forcing a better orientation. Several roof and wall system with east and west orientations work well.

Color is also not a critical issue. It is often better to satisfy the local aesthetic needs of the building with an appropriate color and recover whatever solar heat is available than to have the design rejected because black or other very dark colors are not appropriate.

One element that can raise the cost of a solar re-roof is if numerous obstructions exist on the roof, particularly high volume flow exhaust vents with contaminated air. Many individual vents can be ducted away from the solar roof air intakes, but if there are many widely scattered obstructions that each require time consuming sealing and flashing, then the installed cost will be higher.

6.3 COST ANALYSIS AND COMPARISON

A stand alone White Paper on life cycle cost analysis is included in the appendices. It describes the discounting of the roofing and energy costs in accordance with the FEMP/NIST BLCC program and indices. Figure 19, below shows the cumulative discounted cash flow for a solar roof "as installed" at Gaffney Fitness Center and as could be installed over just the sloped BUR of the Gaffney gym. The appendix discusses the variations in some detail, but key cost elements are discussed below.

The net present value cost of the Gaffney Fitness Facility solar re-roof system, as installed, is a savings of $1,678 per year, $50,363 over 30 years compared to continuing with the existing Built Up Roof (BUR). This combines: 1) solar re-roof costs, 2) avoided Built Up Roof costs, and 3) maximum energy savings for the installed system.

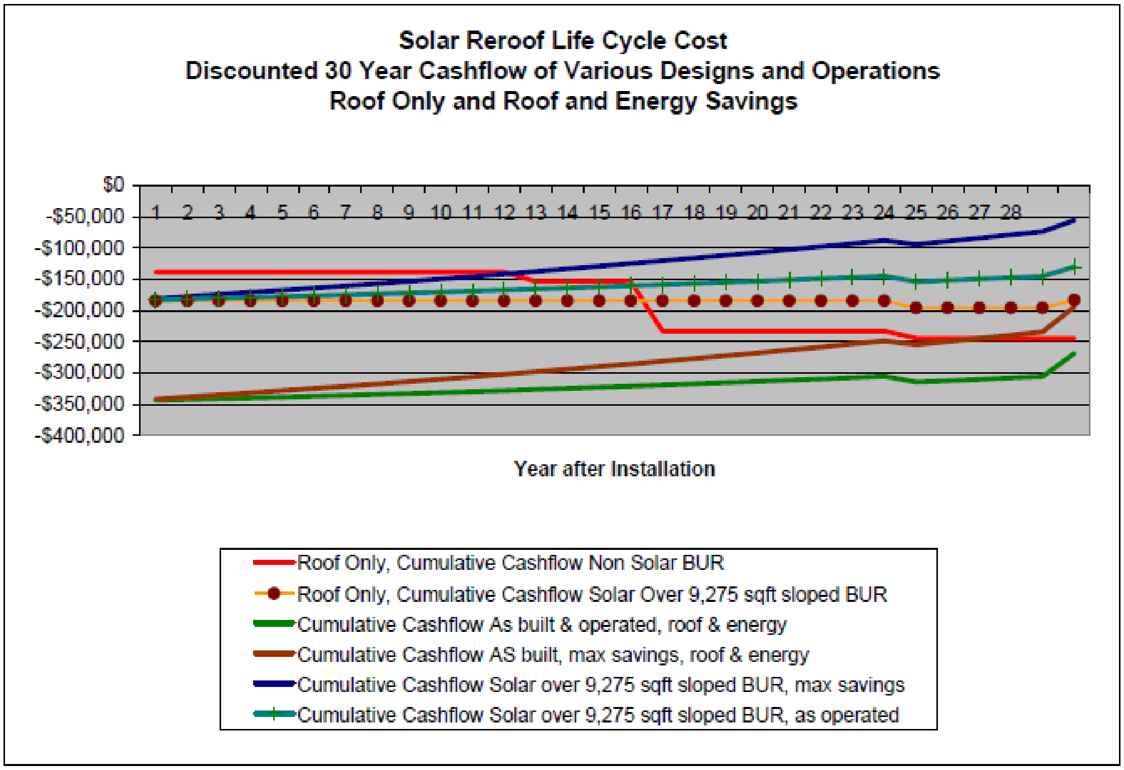


Figure 19 Solar Roof 30 Year Cashflow

Figure 20, shows results from a BLCC analysis of the maximum savings case, and presents similar data to that shown in Figure 19, in a different way. This graph shows the cost of the roof and energy for the case where the Non-solar BURS are installed for 30 years, along with a case where the solar re-roof is installed.

The cumulative discounted cost of each roofing system is shown as well as the combined cost of roofing and energy expenses. For example, the "Total BLCC, Non-Solar cash flow, roof only" case shows the cost of purchasing a new BUR in year1, repairing it in year 13, recovering it in year 17, and repeating the process through year 30. The "Total BLCC cash flow Non-Solar BURs & Gas Cost" curve shows the combined BUR roof and gas energy costs over the 30 year period. The gas energy costs shown are equal to the gas that would have been required to offset the same energy saved by solar. The total 30 year expense for this analysis is $456,601. In contrast, the "Total BLCC Solar Roof & Elec Costs" curve results in a net 30 year expense of $185,546 and a savings of $271,055.

The BLCC analysis for supporting Figure 20 results in even larger savings for the solar re-roof system than the previous chart, which was developed using lower escalation rates drawn from the NIST and OMB escalation indices for outyear roofing expenses and roof salvage value. With the exception of the BLCC report supplied in the appendix, and the chart above, all references to the energy and roofing cost savings in the report use the more conservative values from the separate discounted life cycle cost analysis using the NIST and OMB indices.

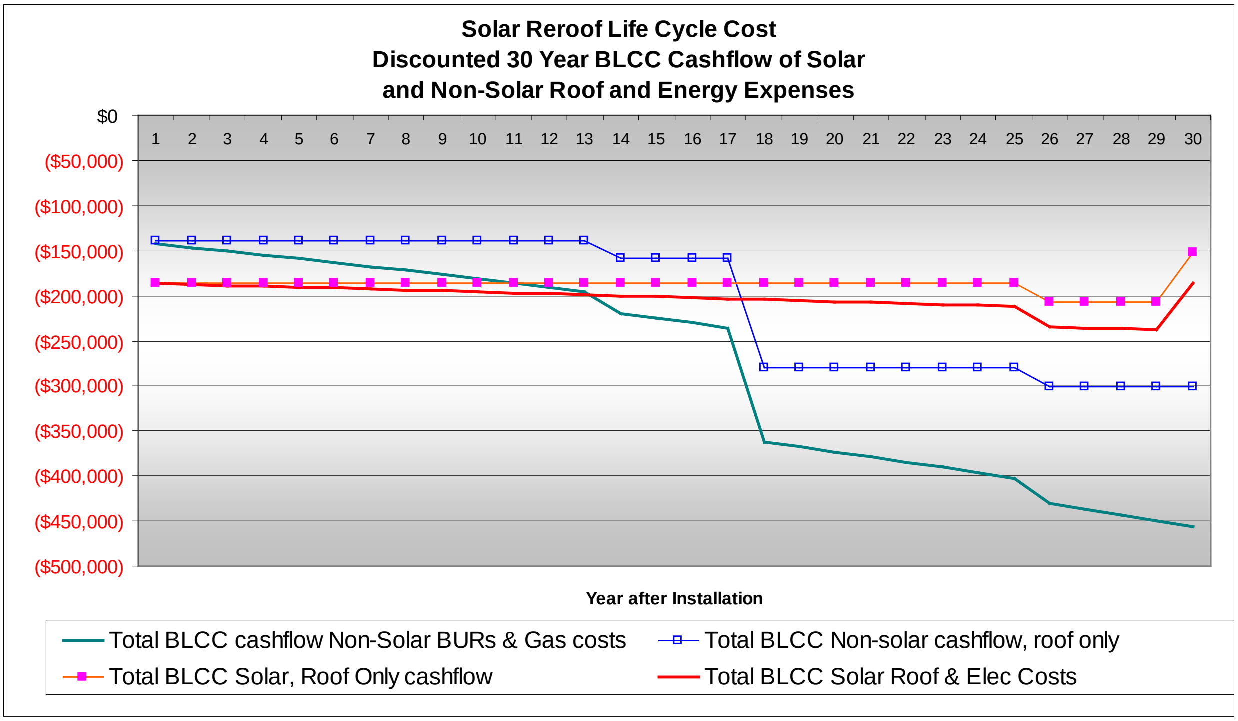


Figure 20 Solar Roof Life Cycle Cost

Figure 21 shows the contribution of each energy and roofing cost savings to the whole, using the maximum energy savings case for the Gaffney Fitness Facility. As discussed above, the Solar re-roof at Gaffney was installed and operated to provided the maximum information on the cost and performance of the solar re-roof. That information enabled the development of a performance model which can calculate energy cost savings for each heating and cooling load under varying solar, weather, and heating load conditions. With the Gaffney facility, the system can be operated to maximize energy savings using only cold water in the heat exchanger and the roofing cost savings can be allocated only at the cost of the roof over the sloped Built Up Roof over the gym. That case is labeled the maximum energy savings or maximum savings case throughout this report.

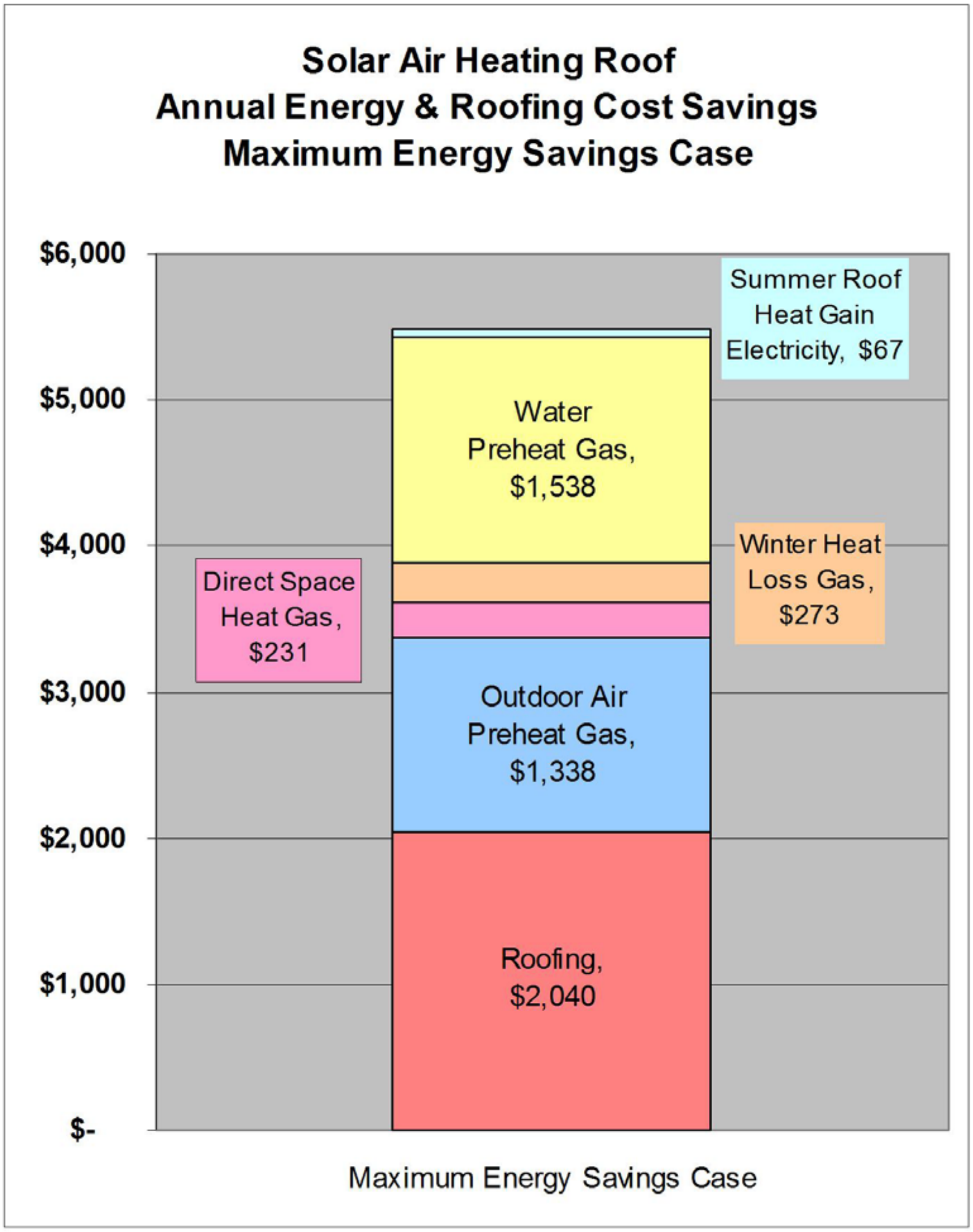


Figure 21 Solar Roof Annual Energy & Roofing Cost Savings

The re-roof of the Gaffney Fitness Center demonstrated 2 kinds of solar roof structures, a re-roof over an existing sloped BUR over the gym and a re-roof over a flat built up roof with a "slope build up" structure. The re-roof over the sloped BUR over the gym requires much less structural support and is much lower cost. The cost allocation for the entire project showed the solar roof section over the sloped BUR was $20/sqft of roof compared to roof cost of $74/sqft section with the slope build up structure over the flat roof section.

The slope build up section of Gaffney, with many areas of new wall and roof to tie into the existing building, is considered to be more expensive than a typical slope build up over a wide flat roof. On an open flat roof, shown in Figure 22, for a different building, structure is simplified and standardized, and new wall surfaces and tie-ins to the old building walls are minimized. The photo shows a more typical slope build up that spans from one side of the roof to the other. Such a system costs closer to $25/sqft, instead of the $74 per square foot for the more complicated Gaffney roof over the flat roof.

Figure 22 Slope Build Up Roof Example

Another approach is to use a low slope solar air heating roof over a flat built up roof. The system at the Army Research Lab Office Building is an example (See Figure 23). That system installed a solar air heating metal roof at a slope of 1/8th inch per 12 inches of run. The structure is 9.5" above the old BUR, the same as the Gaffney structure over the sloped BUR. That 11,000 square foot system would be expected to cost about $20 per square foot installed.

One other system is a metal re-roof over an existing leaking metal roof (Figure 24). Many times the original metal roof is a through fastened roof where fasteners penetrate through the top of the metal panel to attach the roof to structure below. As the roof heats and cools and expands and contracts, the fasteners are a typical source for leaks after a few years. In other cases, the roof is simply decades old and needs replacement. In either case, a solar metal roof can be installed directly over the original metal roof. This is the most economical system because it requires no added insulation and minimal structure of about 2-3" deep over the old metal roof. This system costs about $12-15 per square foot.

Figure 23 Army Research Lab Low Slope Solar Air Heating Roof

Once the roof cost is set, the cost of the fans, ducts, heat exchangers, plumbing, and electric power can be determined. In general, the costs for the Gaffney building are representative of solar air heating roof installations. Fans, ducts, and electric power typically cost $4 per square foot of solar roof. Plumbing cost can be $3 per square foot for a system that uses from 250-3,000 cfm of solar air. This is for systems with short duct runs of less than 50 feet and supply and return piping runs up to 100 feet within the building. Solar heated air has been

Figure 24 Metal over Metal Solar Re-roof

successfully ducted indoors and outdoors up to 120 feet with minimal added cost. The cost for additional length of ductwork and insulation is easily calculated using estimating techniques common to the HVAC trades. The estimation of water heating system costs can also be reliably predicted using standard mechanical estimating techniques.

Most metal roofs can be purchased with a 25-35 year paint guarantee, but the guarantee may not be required as most of the coated coils for metal roofing are given the same paint finish, whether guaranteed or not. The current long life finish is a polyvinylidene fluoride (PVDF) with two popular brand names of Kynar or Hylar. Typical maintenance is to repaint the panels after about 25 years, but this varies depending on the environment. In many salt water coastal environments typical of Navy and Marine Corps installations, the paint life guarantee may not be available.

The fans can be any type required to move the air. Direct drive fans capable of 140F temperature are preferred as there are no belts to change or bearings to grease. Fans have an expected life cycle of 50,000 hours which can be 25 years of service for a fan operating during 2,000 sunny hours per year. As a rule of thumb, the fans will deliver about 1 cubic foot per minute of solar heated air for every 1 square foot of solar roof, but the designer can adjust this to match the load or the roofing area needed. For example, the Gaffney roof was designed for the 9,275 square feet of roofing area that was needed to cover the old, worn out roof. However, the hot water preheat and outside air preheat airflows only needed to be about 3,500 cubic feet per minute for each system to satisfy the loads. The electric power required is about ½-1 watt per square foot or cfm. Ordinary mechanical design principles can be applied to the fan and duct design.

A solar re-roof in a northern climate with a high outdoor air load and a mid to high year round heating load for water, industrial processes, boiler air preheat, or HVAC reheat will make a good, economical candidate building for solar re-roofing. In contrast, a warehouse building in southern latitudes with minimal heating needs, just for a few hours a year of freeze protection, will not be able to take maximum advantage of the solar heat available. A quick assessment of the heating loads, outdoor air, cold water preheat, boiler air preheat, hot water loop heating, or geothermal ground loop heating can determine is the loads will be adequate to generate solar cost savings. A focus on the low temperature incoming air or water sources feeding the conventional heating systems will yield many locations were solar heat can be economically deployed.

In general, savings of 30,000-50,000 BTU/sqft of roof/yr can be expected, with higher savings if there are more low temperature heating/preheating loads.

7.0 IMPLEMENTATION ISSUES

The solar air heating metal roof involves a standard metal re-roof over an exiting worn out roof. There is considerable knowledge within the roofing industry and code reviewers on how the millions of square feet of these metal reroof systems have been installed. The HVAC and plumbing systems are also standard systems using conventional materials and design approaches. There is no special permitting required beyond the standard design review required for any re-roof or HVAC or plumbing modification.

For the solar re-roof of the Gaffney Fitness Center, the metal roof was installed above a built up roof. There is only one only code 'related' document which describes this type of re-roof. It is a Factory Mutual Data Sheet (Ref.4) that is used to guide re-roofing for facilities that use Factory Mutual to support their safe construction and operation of their facilities. It is not a code enforceable requirements document. Traditional code documents rely on requirements for fire protection of materials and assemblies used in the construction, but do not specify how the re-roof materials should be assembled. American Solar followed the Factory Mutual recommendations for assembly and complied with the code requirements for material selection.

One of the challenges in installing solar air heating roofs and re-roofs is that very few of the public works designers, roofing managers, or the architects and engineers they hire are familiar with the solar roofing and re-roofing approach. Often an inquiry about solar re-roofing occurs after the building has been designed and initial cost estimates and budgets are in place and detail design is underway. It is important to inject the solar roof or re-roof approach when the early planning stages are underway. This will increase the likelihood that the full energy savings available from the solar roof can be captured for the next 40 years.

One item to consider in implementing solar roofs is providing funding for the re-roof. Where funding is not available for a solar roof, there is an opportunity to have a third party own the metal roof and solar heating system. Because the solar re-roof is a solar heating system, it is eligible for many Federal and state tax credits. While the government can not take advantage of these tax credits, third party, commercial providers can. This has become common with solar electric (photovoltaic, PV) systems installed on many military facilities. The private contractor installs the system and is paid, over time, by the facility from the energy cost savings that accrue to the facility. Because the private contractor can access the Federal and state incentives, the installed cost after taxes is lower, which can be passed on to the facility through the contractor's lower installed cost. This translates into lower long term energy payments by the facility to the contractor and the utility companies. In many cases, the facility may not have an adequate budget to do the roofing that is necessary, but private contractors can provide the roofing at no upfront cost to the facility, saving the roofing budget for the most important priorities. This approach has already been used with several energy savings performance contracts and utility service contracts that have installed solar air heating roofs and walls.

Warranties for metal roofs can typically be purchased for 20 years for weathertightness and up to 35 years for paint finish. The value of these warranties is that they typically come with another level of inspection by the warranty organization. This can increase the chances of having a well designed and installed roof. However, there is a cost to pay for the warranty. Since there is little that can go wrong with a well designed metal roof once it is properly installed, a long term warranty is not often of great value to a building owner. Often a better choice is a short term weathertightness warranty to ensure the roof does not develop a problem in the first few years.

8.0 TECHNOLOGY TRANSFER

8.1 COMMERCIALIZATION AND IMPLEMENTATION

The solar air heating metal roof is an existing roofing system available in the commercial marketplace. The system has been installed using direct Federal contracting, and through Energy Savings Performance Contracts and Utility Energy Service Contracts. It has been sought out by Energy Service Companies as an addition to the ESPC they offer to their Federal customers. However, in some cases, the engineering evaluators for those companies have overlooked the concept either by lack of knowledge or simply because they did not have validated information on the installed cost and energy savings potential. The results of this project will provide the information necessary to overcome those concerns on future projects.

8.2 TRAINING REQUIREMENTS AND RESOURCES

Part of the purpose of this ESTCP project is to expand the documentation and validation of the technology to increase awareness in the design community. However, it is not widely known. Toward that end, American Solar has inserted references to the project on its website and spoken of the project at national conferences including the ESTCP Symposium in 2012. The concept was recently introduced to the Department of Energy during their Solar Hot Water Roadmapping Session and has been included in the recommended program plan.

American Solar intends to publish the final report and the appendices on its website for others to use to expand the industry. A particular target group will be the roofing component manufacturers who stand to increase sales if the solar air heating roof is more widely adopted. American Solar will also target several trade magazines to target the roofing professionals who serve the roofing and real estate industry. These professionals include architects, engineers, roofing consultants, and building envelope specialists who are involved in the design of roofing systems for new construction and more importantly for re-roofing and retrofit of existing roofing systems. These professionals require confidence that the solar air heating roof systems can be easily implemented with predictable weathertight performance and with economical performance that provides better economics than traditional roofing and heating energy systems.

8.3 DESIGN COMMUNITY IMPACTS

Members of one particular target group are the architects and engineers who are the first to plan and design roofs and mechanical system for buildings. This group uses a variety of topical standards and goals to improve the quality and performance of new and renovated buildings. These standards, such as LEED incorporate energy credits or requirements. Within the LEED system, the solar re-roof can impact as many as 49 points for energy, recycled content, innovation, air quality and other elements. American Solar intends to target trade publications, websites, and speaking engagements at local chapter meetings to increase visibility of the solar air heating re-roof and its benefits.

APPENDICES

APPENDIX A: PERFORMANCE ASSESSMENT METHODOLOGIES

There were 6 different analyses conducted as part of the Gaffney Fitness Center Solar Air Heating Metal Re-roof. Each analysis is discussed in its own section of this Appendix A. The Sections include:

1. Domestic Water Preheat,
2. Outdoor Air Preheat, Direct Space Heat, and Roof Heat Loss Reduction,
3. Solar Roof Vs. Cool Roof,
4. Fire Protection,
5. Life Cycle Cost, and
6. Radiant Barrier

Numbering is Appendix A-1, A-2, Etc.

There is some duplication between the Appendices, as they were written to permit a reader with an interest in a particular topic (e.g., Domestic Water Preheat) to find all the pertinent information on that topic in a single appendix. This should permit a reader to understand and analyze the particular topic without the need to refer back and forth to other sections. The goal is to provide a characterization of the installation, testing, analysis, and results related to each particular topic in a way that supports both the findings extracted to the main body of the report and to support future designs and installations to economical solar air heating roof.

The life cycle cost section , Appendix A-5 includes a detailed discussion of the cost of the Gaffney solar roof and a discounted cash flow analysis using the NIST and OMB discounting factors available from the Federal Energy Management Program.

A separate Appendix, Appendix B, includes an additional Life Cycle Cost Analysis output using the BLCC program.

Appendix A-1: Domestic Water Preheat,

Solar Air Heating Roofs: Air to water heating performance

Executive Summary:

Background: American Solar, Inc. evaluated the capability of its solar air heating roof system to deliver heated water for domestic hot water heating, using an air to water heat exchanger. This analysis is part of a larger project to document the overall annual energy and life cycle roofing benefits of a solar air heating roof.

The project is funded by the Department of Defense Environmental Security Technology Certification Program (ESTCP) (Ref. 1). The Solar roofed building is the Gaffney Fitness Center at Fort Meade, MD.

The following summarizes the analysis with a focus on addressing 2 issues:

1. The capacity of the solar air heating roof to heat water using a solar air to water heat exchanger.
2. Modeling of the solar air heating roof to provide prediction of the water heating capacity based on typical meteorological year data and cold water temperatures.

A series of temperature sensors were installed within and around the new solar roof system. This included a set installed in an air to water heat exchanger enclosure and on the preheat storage tank and the pump. These sensors, along with air flow measurements made for each fan, provide air and water temperatures and mass flows that permit the calculation of heat transfer from solar air to the preheat water and from entering cold city water to the preheat water returning back to the building.

Results:

The following list provides selected important results from the project to help facility managers understand the capacity, performance, and economics of the system at the Gaffney Fitness Center and to detail a few of the specific performance requirements identified in the Demonstration Plan for the project. An extended list of findings and results is provided at the end of the appendix and presented in the "Performance Results" section of the full report.

The Solar Air Heating Roof and Air to Water Heat Exchanger:

1. Delivered an average of 2 gallons per minute of preheated water to the building.
2. During July, the peak solar preheat temperature for water returning to the building was 124.4F with cold city water entering at 82.7F.

3. During July, the peak water heating capability recorded was 31,700 BTU/hr and the system provided an average of 125,000 BTU per day of solar preheat to the cold water intake of the building hot water heating system.
4. During July, the system delivered solar heated water to the building for an average of 11.75 hours per day, with fans and pump operating 9.25 hours per day and heat from daily storage providing 2.5 additional hours of heat.
5. The system will provide heat to the water at a rate of 51.6 million BTU/year, 13,057 BTU/sqft/yr, 1,088 BTU/sqft/mo, and peak of 13.9 BTU/sqft/hr. With a larger water heating demand in the building, the installed solar air to water heat exchanger can provide an average solar air to water heating capacity of 213.4 million BTU/ year, 53,947 BTU/sqft/yr, 4,496 BTU/sqft/month, and peak of 64 BTU/sqft/hr.
6. With one fan operation, the water heating system will produce 47.6 million BTU/year. With a larger water heating load and one fan operation, the installed solar air to water heat exchanger, can provide an average solar air to water heating capacity of 159.0 million BTU/sqft/yr.
7. With two fan operation, the system will provide an average of 1.8 times as much heat energy as the equivalent electric energy used to power the fans and pump.
8. With one fan operation, the system will provide an average of 2.8 times as much heat energy as the equivalent electric energy used to power the fan and pump. With a larger water heating demand in the building, the system will provide an average of 9.4 times as much heat energy as the equivalent electric energy used to power the fan and pump. During the peak predicted hourly performance, with one fan and a larger water heating demand, the system provides 33.6 times as much heat energy as the equivalent electric energy required to run the fan and pump.
9. The installed solar air to water heat transfer system is capable of providing much more heat/square foot of solar roof than was required to meet the hot water load in the Gaffney Fitness Center due to the large roof installed for "roofing" purposes.

Introduction:

Gaffney solar re-roof and hot water preheat system

The Solar re-roof of the Gaffney Gym involved two types of metal roof retrofit and the installation of a solar air to water heat exchanger. The primary area with 7,715 square feet of solar roof, involved a retrofit of the metal roof installed a few inches above the existing sloped gym roof. This area is divided into 4 separate zones, for fire protection reasons. Zone 1 and 2 are used to supply solar heated air to the hot water preheat system and have a total area of 2,395 square feet.

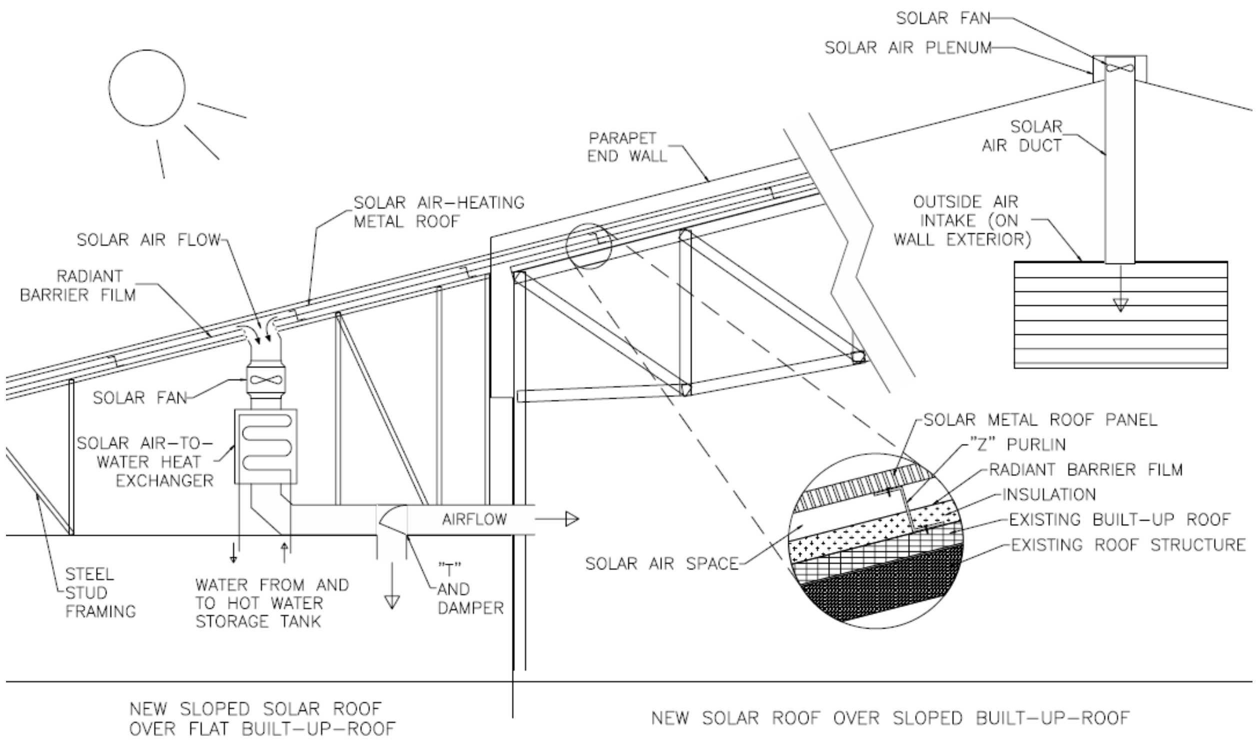


Figure A-1 , 1 Concept Schematic Section

A fifth zone, of 1,560 square feet, was created by the installation of a solar metal roof over a low slope roof using a 'slope build-up' system. The 'simplified' sketch Figure A-1,1 shows a schematic of the primary area to the right and the slope build-up area to the left. The area to the left created a solar mechanical room that was built on top of the existing Built Up Roof (BUR). The solar air to water heat exchanger was installed in the mechanical room. A photo of the installed system, taken from the reverse angle, is shown in Figure A-1,2.

Figure A-1 , 2 Solar Mechanical Room

Domestic Hot Water Heating System

The solar heated air collected from the roof is used to preheat cold city water before it is introduced to the domestic hot water heating and storage system.

Insulated solar ductwork (photo foreground left) draws air from the solar roof to the air to water heat exchanger (elevated ~4') then exhausts the heated air outside (hidden behind the heat exchanger), or into the gym, shown to the left of the heat exchanger, penetrating the white corrugated wall. Water pipes in an insulated metal enclosure (shown to the right of the heat exchanger) supply 'colder' water to the heat exchanger and return preheated water to the preheat storage tank located in the basement mechanical room.

A schematic of the air to water piping and storage system is shown in Figure a-1,3. See Figure A-1, 25 at the end of this appendix for vertical section and boiler room arrangement.

The building's existing domestic hot water system consists of a condensing, gas fired boiler heating an 80 gallon storage tank. Hot water is constantly circulated from the tank through the building for sinks and showers. (A backup system used during maintenance periods uses the pool heating boiler to heat DHW via a heat exchanger.) Cold city water is supplied to the boiler. When water is drawn from the sinks or showers, cold city water enters the boiler - tank loop. When the hot water temperature in the tank and building loop drops below 130F the boiler turns on to heat the water in the tank.

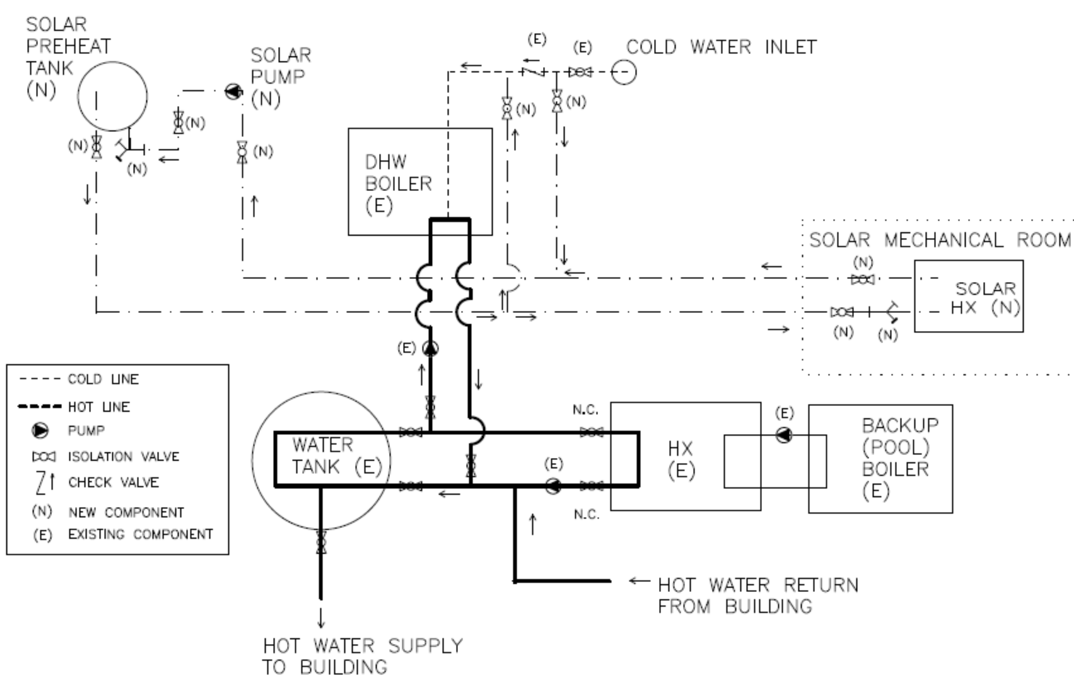


Figure A-1 , 3 Solar Water Piping Plan

The solar preheat system is set up as a parallel loop to the cold water line feeding the boiler. When hot water is drawn from the sinks or showers, the cold water that enters the boiler flows through both the existing cold water line and through the solar preheat system. The cold water flowing into the solar loop is matched by a flow of preheated water flowing back into the cold water inlet of the boiler loop. Thus, a portion of the water entering the boiler is solar preheated.

The solar preheat system draws cold water from the cold city water main. The cold water is mixed with preheated water returning to the preheat tank from the solar heat exchanger, before being pumped into the bottom of the preheat storage tank. Preheated water flows out through the top of the preheat tank and back to the heat exchanger and/or to the boiler cold water inlet. The solar preheat line returning to the boiler cold water inlet is located downstream of the cold water supply to the solar preheat system. The solar supply and return are separated by the existing check valve in the cold water supply to the boiler, which prevents short circuiting of the pumped preheat water through the cold water supply line instead of through the solar heat exchanger.

When no water is being drawn for sinks or showers, and the solar water heating system is energized, solar preheated water is continuously circulated through the solar preheat tank to the solar heat exchanger in the solar mechanical room and back to the pump and tank. During these periods all the solar heating goes to raising the temperature of the water in the preheat tank. During periods with little or no demand for hot water, the temperature in the preheat tank will rise to within a few degrees of the solar air temperature in the heat exchanger.

When there is a draw of hot water from sinks or showers, the blended cold water and preheated water returning from the heat exchanger water will enter the bottom of the preheat tank where it is further blended with water in the tank. During periods of light demand, the solar heat from the heat exchanger may be delivering heat to the preheated water more quickly than the heat drawn off via preheated water to the sinks and showers. In that case the temperature of the preheat tank (and preheated water returned to the building) will continue to rise.

When there is a high demand for hot water and a large flow of cold water into the preheat system, the temperature in the preheat tank and solar heat exchanger loop may drop. This typically occurs when gym use peaks during the early morning, at lunch time, and at the end of the workday from the afternoon through early evening. This drop in preheat system temperature is visible on time-temperature plots even when factoring out the temperature variations that occur from changing solar insolation and wind speed.

<u>Temperature and flow measurement</u>

To document the thermal performance of the solar roof and air to water heating system, temperature measurements were made with fixed, 10k ohm thermistor sensors embedded in the solar roof and arranged at various locations in the solar ductwork and piping. Readings from these sensors were logged every 15 minutes using LabJack data logging hardware and DAQFactory Software that recorded readings directly to a file on a computer hard drive. The system records voltage readings across the thermistors which indicate the thermistor resistance and temperature.

During the commissioning of the solar heating system, air velocity measurements were taken in all ducts connected to the air to water heat exchanger to document the air flow in each duct. With fixed speed fans, the air mass flow will be essentially constant whenever the fans are running.

Precise water flow measurement in the loop between the preheat storage tank and the air to water heat exchanger were measured using a permanently installed metering valve that was set to match the flow of 11 gpm. The fixed speed pump provides a constant circulation through the storage tank. A second measurement of the water flow is provided by confirming the heat transfer from air to water and the water temperature difference in the heat exchanger. Since the heat transfer from air must equal the heat transfer to water at the heat exchanger, we can accurately determine the water flow rate from the heat transfer divided by the water temperature difference. This water flow metering along with the water temperature difference provides two means to measure the solar air to water heat transfer in the heat exchanger.

As mentioned above, the preheat system is set up as a parallel loop to the existing domestic cold water to hot water path. (See Figure A-1,4). With this parallel arrangement there will be a variable water flow in the solar loop as cold water simultaneously enters the solar loop and the existing cold water feed to the domestic hot water boiler when hot water is drawn from the domestic hot water system.

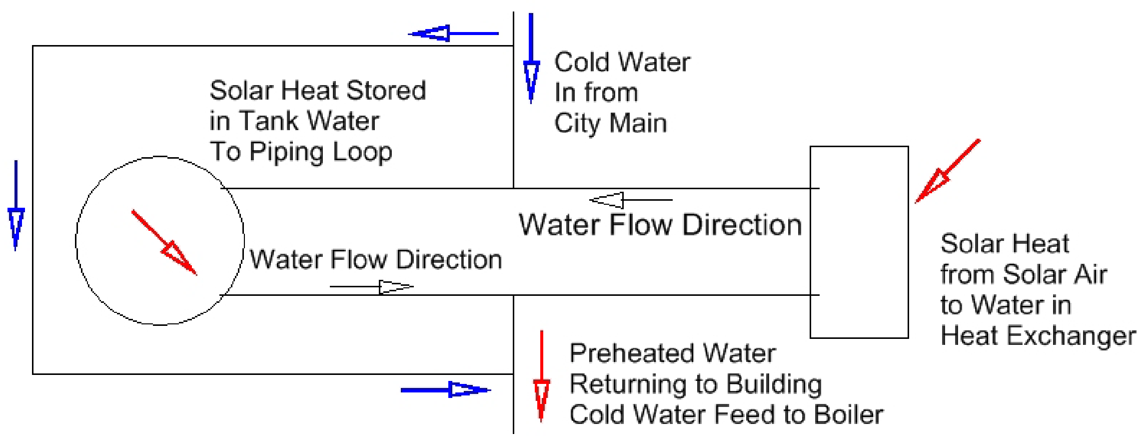


Figure A-1, 4 Parallel Piping Schematic

Because the cold water flow in, and preheated return to the domestic hot water system, constantly vary with hot water use in the building, the most reliable measure of heat transfer is by documenting the heat transfer in the solar air passing through the air to water heat exchanger, as heat out of the air equals heat into the water. By also measuring the temperature of the 40 gallons of water in the preheat tank, we can determine how much heat went into (or out of) the preheat tank during a given time period. The total heat transferred to the building is equal to the heat transferred in the heat exchanger minus the heat gain in the preheat storage tank.

A second ‘indication’ of the solar heat input to the system is based on the temperature difference between cold city water entering the solar loop and the preheated water going back into the water pipe that feeds the building domestic hot water heating system.

Because we can

1. determine the total heat transfer in the heat exchanger and
2. the warming or cooling of the preheat tank and
3. the supply and return water temperatures to and from the building,

we can determine the quantity of preheated water flowing into the building.

During the solar operating hours in July, with the fans and pump on, the preheat water temperature averaged 15F hotter than the cold water supply and reached a maximum of 46F hotter during one 15 minute reading. Figure A-1, 5 shows temperatures of

- cold water in,
- return water to building domestic hot water system,
- temperature difference between the two, and the
- fan & pump On-Off times

for a one month series of readings. For reference, the existing building domestic hot water loop circulates at 130F.

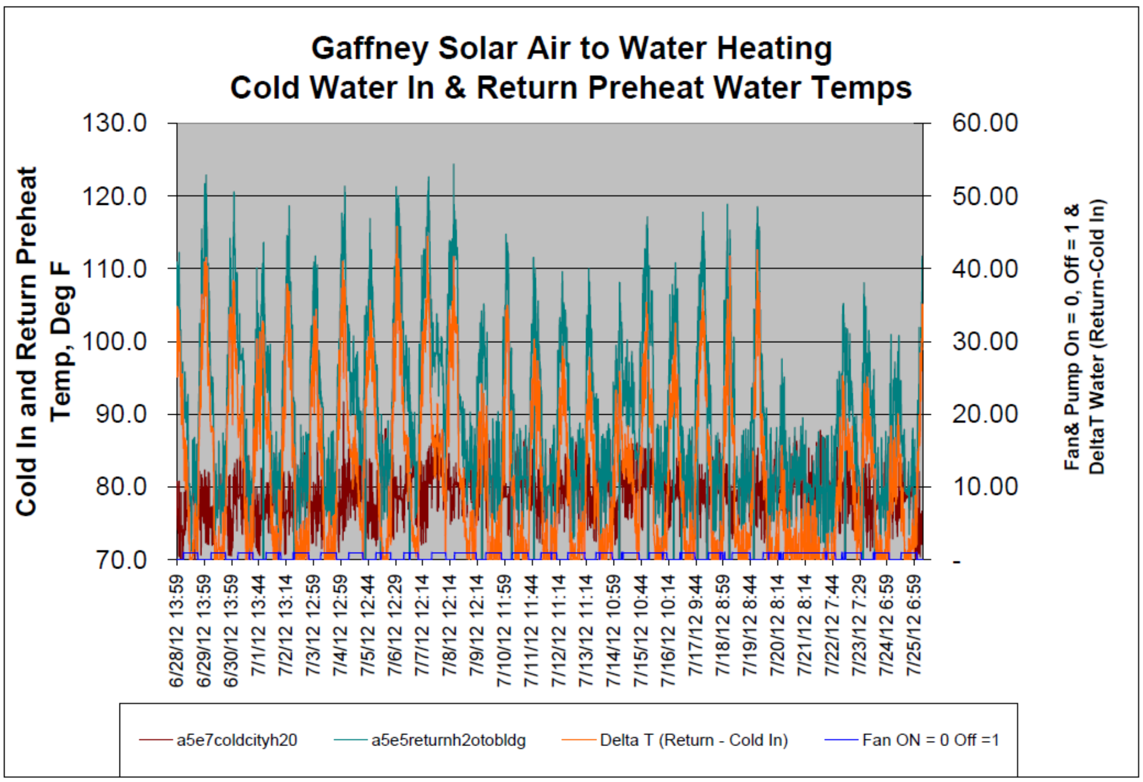


Figure A-1 , 5 Cold and Return Water Temps

During the one month period, cold water entered at ~70-85F and solar preheated water temperatures regularly reached 100 to 120+F. During all ON hours from 6/28 thru 7/25, the water out of the heat exchanger averaged 100.1F. The average water temperature returning from the preheat tank to the building cold water inlet of the boiler loop was 94.1F.

This 94.1F average preheat temperature slightly understates the average because there is residual heat stored in the 40 gallon preheat tank after the fans and pump shut off. This preheated water will continue to flow to the building cold water loop as hot water is drawn from the sinks and showers during the OFF hours. The preheated water in the tank will also slowly lose heat to the surroundings, and will eventually be completely filled with cold water entering the system. At that point it will reach the temperature of the cold water entering the system. For example, the heat available in a storage tank, that is 20F warmer than the cold water entering the system, is about 6,700 BTU.

Figure A-1,6 shows the details of the temperature measurements for a one day period, 7/6/12. This chart shows the detail of:

- the cold city water into the system before the pump and tank,
- the solar water into and out of the heat exchanger and
- the preheated water returning to the building cold water intake of the domestic hot water system,
- the fan/pump On-Off time, and
- the gym operating hours for that day.

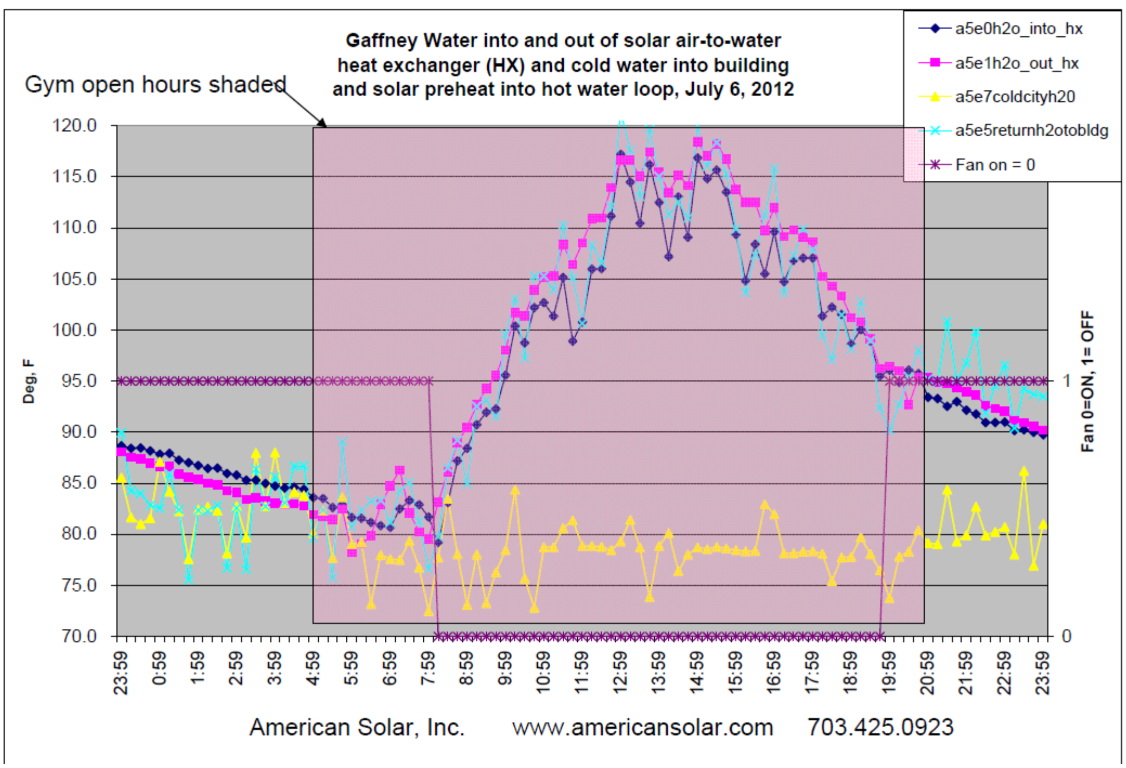


Figure A-1 , 6 Solar Water System Temps

Return water temperature, outside the solar operating hours of 8 AM to 8PM (8:00 to 20:00 in chart), when the pump and fans are OFF, shows a slight decline as the preheated water in the tank slowly cools during the nighttime hours. The slow cooling of the water into and out of the insulated heat exchanger enclosure can also be seen. Once the pump and fans start in the morning the water is quickly heated. Water in the preheat tank that returns to the building hot water system increases in temperature at about 10 degrees per hour just after the start up of the solar heating system. On this particular day, the solar system provided preheated water from 8:00 AM through closing time at 9PM (21:00), or 13 out of the 16 hours that the gym was open.

Figure A-1, 7 repeats the plots of cold water from the city main and return water to the building domestic hot water inlet. It also plots the temperature difference between the two. While the general shape of the curve of return temperature and temperature difference follow the daily solar insolation curve, shown below the graph, the short term temperature variability is due to changes in cold water flows into the system and to a lesser extent solar air temperature changes caused by short term changes in solar insolation (clouds) and wind across the roof (shown plotted from local weather station data below). The weather and solar data is plotted using Eastern Standard Time (EST) and the Solar heating system temperature sensor data are plotted using Daylight Savings Time (EDST), e.g. in July, 13:00 EDST = 12:00 EST. See vertical dashed line for coincident times.

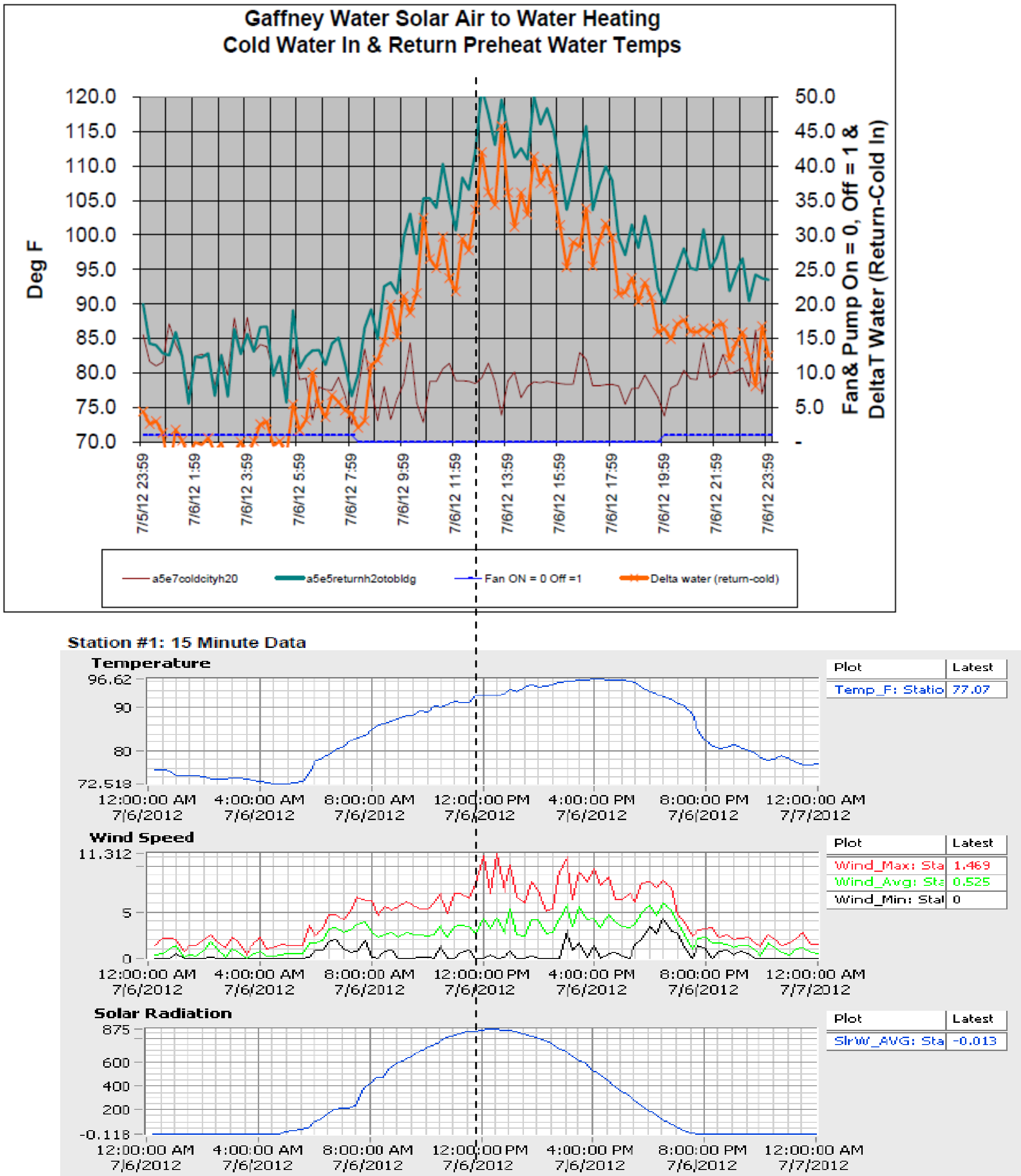


Figure A-1 , 7 Solar Water Temperatures and Weather

The chart in Figure A-1 8 shows more detail of just the ON hours for the solar fans & pump. It also shows the temperature difference for the air and the water entering and

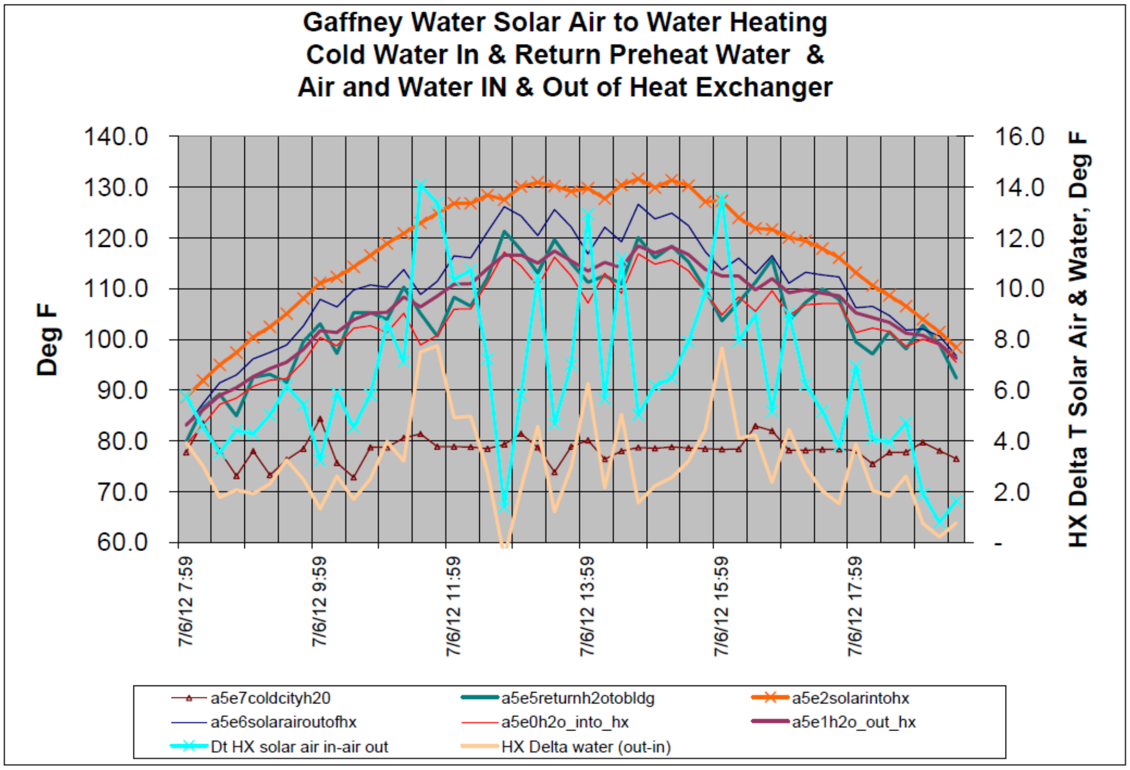


Figure A-1 , 8 Hourly Changes in Solar Water Temps

exiting the heat exchanger. Note that there are two pronounced peaks in the 'HX Delta water' values. These values coincide with drops in the temperature of preheat water returning to the building. This is assumed to be caused by increased draws of hot water, which causes increased cold water to enter the solar preheat tank, and cool the return water. Both of these peaks occur around noon (lunchtime) and at 16:00 (end of the work day). During both of these periods, the gym sees increased occupancy, which generates more hot water demand and more cold water flow into the solar preheat system.

Similarly, there is a low point in the 'HX Delta water' value at 12:59. This low point coincides with a high temperature of water returning to the building and very low 'DT HX solar air'. This corresponds with the mid day hours after lunch where there is minimal activity in the gym and low water demand resulting in most of the solar heat going to raise the temperature of the preheat tank. High storage tank temperature results in high water temperature being circulated to the heat exchanger. As preheat water temperature approaches the solar air temperature, heat transfer across the heat exchanger declines as shown as the 'HX Delta water' decreases.

<u>Solar air to water heat transfer</u>

The calculation of heat transfer in the system combines the temperature and air and water flow measurements to generate overall thermal performance of the roof and solar air-to-water heating system in terms of BTU of heat transfer to the building. The data collected as part of this DOD ESTCP project was designed to demonstrate and document the solar water heating capability of the solar air heating roof.

During the early testing in late June and July, 2012, temperatures were recorded at 15 minute intervals at all the temperature sensors. Solar fans 1&2 turn ON when the solar roof air is nominally 8 F warmer than the water at the top of the preheat storage tank in the basement mechanical room and turn OFF when the solar air is less that 4 F warmer than the water at the top of the storage tank.

On July 6th, during the daytime and evening hours, from 8:15 to 19:45, the solar fans were running, drawing outdoor air down from the ridge air inlets and soffit and fascia inlets, through the solar roof air space, to the outlets in the solar attic/mechanical space created below the eaves of the old gym roof. That solar air was drawn through the air to water heat exchanger enclosure by solar fans 1&2, and then exhausted outside.

Water was piped to and from the basement mechanical room, through the building, and up into the air to water heat exchanger in the solar mechanical room. The pump is a fixed speed pump.

Figure A-1, 9 shows: the temperatures of the different sensors in the air to water heat exchanger, the cold water supply and hot water return to the building, and the fan/pump run times over a one day period.

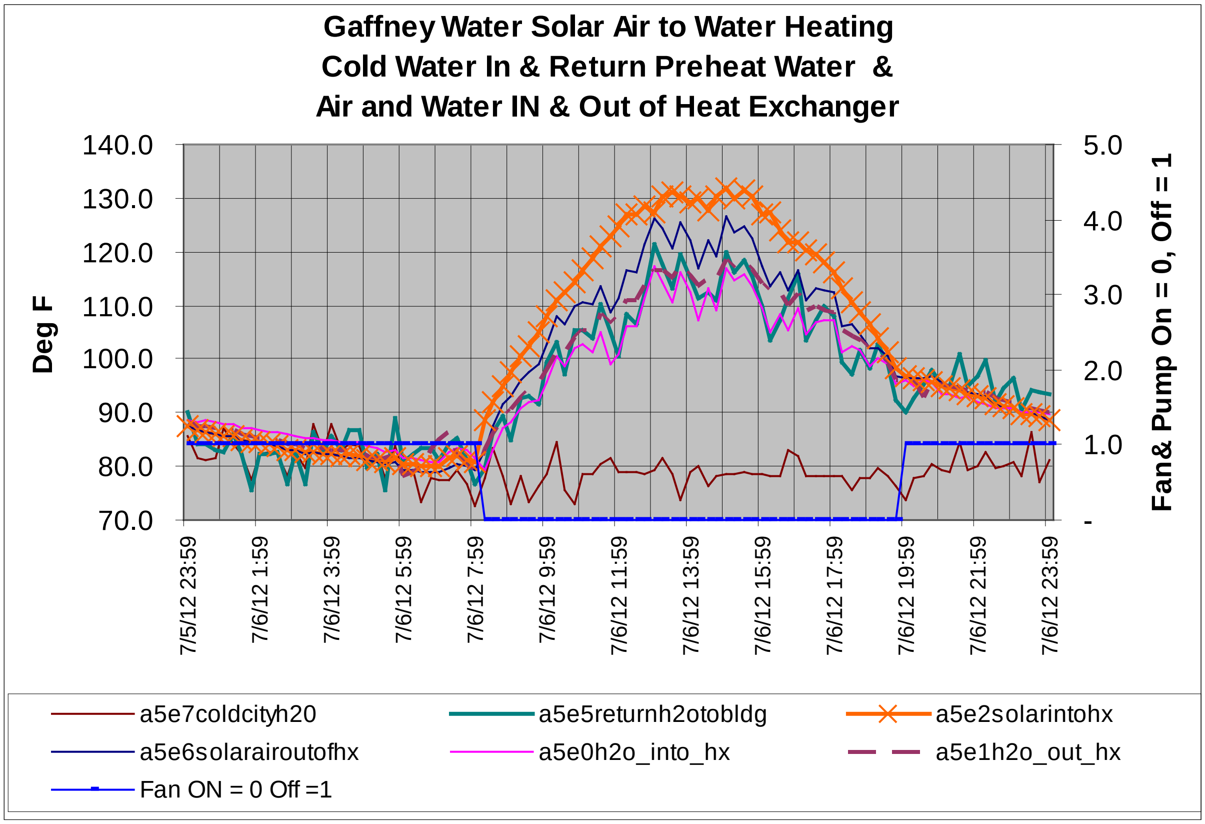


Figure A-1 , 9 Heat Exchanger Temperatures

Sample calculations of heat transfer and flow for this one day period follow when operating with 2 solar fans running. A later section describes the case with only one solar fan running.

<u>Two Fan Operation</u>

During the one day on July 6, 2012, the heat transfer from the solar air to the water can be calculated using the temperature difference of the solar air into and out of the heat exchanger, the mass flow of air and the specific heat of air.

The formula for the heat transfer is $\dot{Q} = Cp \times \dot{m} \times dT$

Where
$\dot{Q}$ is the heat transfer in BTU/hr
Cp is the specific heat of air = 0.24 BTU/#dryair/DegF.
$\dot{m}$ is the mass flow in #dryair/hr = 3320 cfm x 60 min/hr / 14.6cuft/#dryair = 13,644#dryair/hr
dT is the temperature drop in air across the heat exchanger = 13.4F at 11:59 , and average 6.7F for all ON fan hours

For example, at 11:59 the temperature difference is 13.4 F so the heat transfer is:
$\dot{Q}$ =0.24 x $\dot{m}$ x dT = 0.24 x 13,644 x 13.4 = 43,800 BTU/hr. See Figure A-1,10.

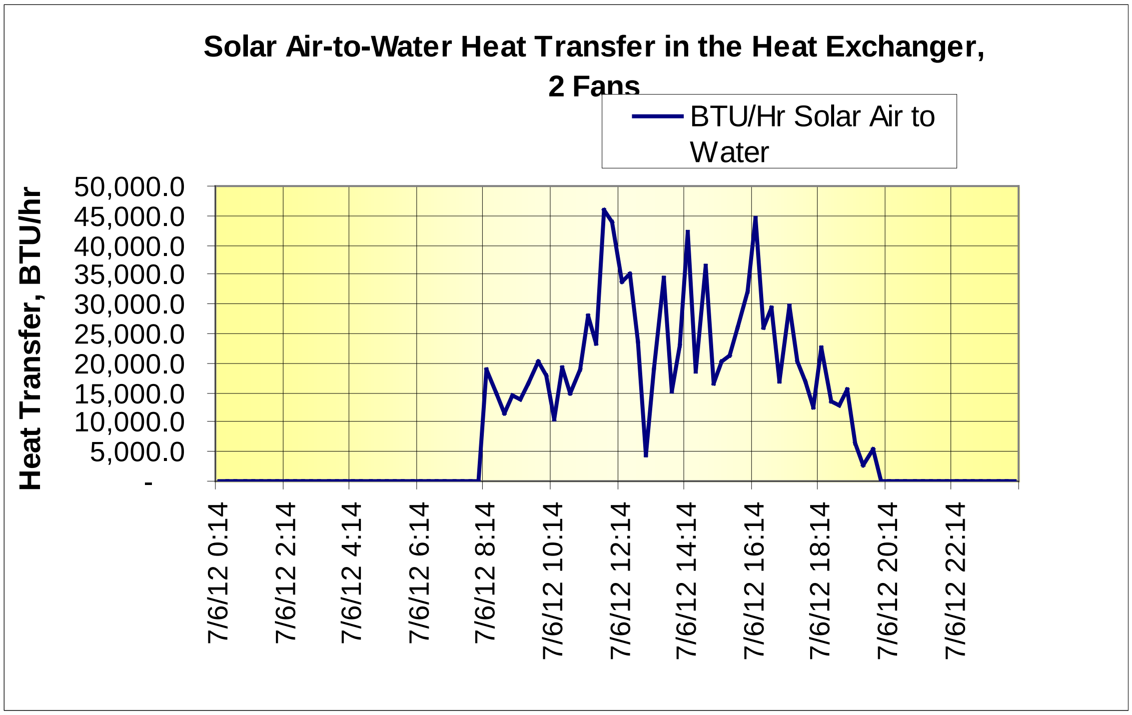


Figure A-1 , 10 Heat Exchanger Heat Transfer

During this 24 hour period, the solar fans for zones 1&2 ran from 8:15 to 19:45, 11.5 hours. The average temperature difference during ON hours was 6.7 degrees F. So, the heat transfer for the day is:

$\dot{Q}$ =0.24 x $\dot{m}$ x dT X Hours = 0.24 x 13,644 x 6.7 x 11.5 = 252,300 BTU/day on 7/6/12.

For the period from 6/28/12 to 7/25/12 we calculate an average solar air temperature drop in the heat exchanger of 5.2F during 259.8 ON hours. This provides a total heat transfer to the water of 4.4 million BTU over the 27 day monitoring period.

Heat transfer from preheat tank to building

As mentioned above, the total heat transferred to the building is equal to the heat transferred in the heat exchanger minus the heat gain in the preheat storage tank. The solar heat transfer to (or from) the water in the preheat storage tank can be measured by the increase in temperature of the 40 gallons of water in the preheat tank over a set time period. This value is best measured by the temperature of the water leaving the top of the tank and returning to the building cold water intake.

As mentioned earlier, a change in temperature of 20F of the 40 gallons equals 6,700 BTU. By reviewing the initial operating hours on July 6th, from 8:15 to 10:15, the temperature in the return water rose from 80F to 103F. This represents a heat transfer of 7,700 BTU in 2 hours, ~3,850 BTU/hr. During that same 2 hour time period, the temperature drop in solar air moving across the heat exchanger was 4.7F, producing a heat transfer in the air of 15,400 BTU/hour, or 30,800 BTU/2 hour. We assume that all the heat transfer from the air went into the water circulating in the solar loop.

Since the total heat transferred to the building is equal to the heat transferred in the heat exchanger minus the heat gain in the preheat storage tank, we can use the values above to calculate a value of the heat transfer of the return water entering the cold water inlet to the boiler. During these first 2 hours the heat exchanger is transferring 15,400 BTU/hr from solar air to the preheat water loop and tank, of which, 3,850 BTU/hr goes to heating the water in the tank. So, during these two morning hours, 11,550 BTU/hr (=15,400-3,850) is the heat being returned to the building at the cold water inlet for the boiler.

Later in the day, when the preheat tank temperature levels off, a smaller percentage of heat goes into raising the tank temperature (heating the tank) and a greater percentage of heat goes into heating the return water for the boiler.

Water volume flow calculation

Solar heat exchanger water volume flow We can use the temperature changes and heat transfer in the heat exchanger to calculate the water volume flow in the system. Since the heat transfer from the solar air is equal to the heat transfer to the water in the heat exchanger, we can calculate the water flow from the formula

$\dot{Q}$ =cp x $\dot{m}$ x dT,
where cp for water = 1.0,

At 11:59 7/6/12, $\dot{Q}$ = 43,800 BTU/hr from the solar air in the heat exchanger must equal the heat transfer into the water in the heat exchanger. During that time, the temperature rise in water passing into and out of the heat exchanger was 7.75F.

So, the mass flow of water is 43,800 / 7.75 = 5,652 #/hr or 11.3 gallons/min (gpm).

This is reasonably close to the design value of 10 gpm for the system and the setting of 11 gpm on the metering valve.

Preheat water volume flow return to building
As mentioned above, during the 2 hour period between 8:15 and 10:15, on July 6th, after the morning startup, 11,550 BTU/hr (=15,400-3,850) is the heat being transferred into the cold water inlet (return to the building) for the boiler. This heat transfer is equal to the mass flow of water times the temperature difference between the cold water into the solar preheat system and the preheated water returning to the boiler intake. The average temperature difference between the cold water into the tank and the preheat water out of the tank returning to the boiler is 13.1F. So, during this period, we calculate an average of 880 pounds per hour (11,500/13.1 = 880) of preheated water is supplied to the building cold water inlet to the boiler or 106 gallons per hour, 1.8 gallons per minute.

Using a similar approach, during the 15 minute period at 11:59 the temperature of the water in the tank dropped by 1.97F giving up 1,500 BTU/hr to the preheat loop, the heat exchanger solar air dropped 13.38F adding 43,800 BTU/hr to the preheat loop for a total of 45,300 BTU/hr into the preheat loop. The temperature difference between cold water and return water was 21.79F. So, the cold water flow into the preheat tank which matches the return water to the building was 2,079 pounds/hr (45,300/21.79) or 250 gallons per hour, 4.2 gallons per minute.

Electrical energy use

During the July tests described above, the system operated with solar fans 1&2 and the solar pump running. Each solar fan draws 12.01 amps at 114 VAC, or 1369 watts. The solar pump is rated at 1/3 horsepower, or 248 watts. Power for the control system is less than 20 watts. So total power for 2 fan operation is 3006 watts, or 10,260 BTU equivalent. (See later section on 1 fan operation.)

The average hourly heat transfer over the July 6 day described above was 21,939 BTU/hr. So, the solar heating system delivered 2.1 times as much heat energy as the equivalent electricity consumed. At the peak hour around 12:30 the system averaged a heat transfer of 39,735 BTU/hr. During that hour the system delivered 3.9 times as much heat energy as the equivalent electric energy required to run the system.

During one peak hour on June 30 at 2PM, the systems averaged, 45,437 BTU/hr of heat transfer. During that hour, the system delivered, 4.4 times as much heat energy as the equivalent electric energy required to run the system.

Prediction of Monthly and Annual Solar Air to Water Heat Transfer

The calculation of heat transfer above is from the measured temperatures of air and water around the system, with particular focus on the temperature difference at the heat exchanger. By taking many measurements across the heat exchanger, we can develop a characteristic curve of heat exchanger performance based only on the solar air and cold water temperatures entering the heat exchanger. We can also develop an expected hourly performance based on the measured solar temperatures and the weather and solar conditions expected at a particular location. The following sections discuss the determination of the performance based on predictions developed from the measured data from the Gaffney Building and local weather and solar conditions.

Prediction of heat transfer in the air to water heat exchanger is dependent on the ability to predict;

1) the temperature of the solar air and
2) temperature of the preheated water

supplied to the air to water heat exchanger.

These predictions of air and water temperature can be made over monthly and seasonal periods using values derived from a regression analysis of the Gaffney data. While these longer term predictions provide valuable results, caution is required when applying the values to short term daily and hourly analysis. 'Precise, short term' hourly prediction of solar air temperature can not be made due to the variability of weather conditions (clouds, wind, etc.). Precise hourly prediction of the preheat water temperature at the Gaffney gym heat exchanger is also not possible given the varying hourly demand based on occupancy. But accurate monthly average predictions for both solar air and preheated water can be made using values derived from a regression analysis of the Gaffney data.

Monthly and annual prediction of solar air temperature and weather data can be made using the values generated from the Gaffney data and weather and solar data from files such as typical meteorological year (TMY) (Ref. 5) data or Air Force or NOAA data. Predictions based on monthly data smooth out the hourly variability which permits accurate estimates of long term performance.

Water temperature to the heat exchanger is the other value of importance in predicting heat transfer in the air to water heat exchanger. It is a function of cold city water temperature, solar heating at the heat exchanger, and the instantaneous demand for hot water in the building, which leads to an inflow of cold water to the solar preheat systems and the heat exchanger. Like the solar air temperature, the instantaneous demand varies widely from hour to hour. This prevents prediction of the exact water temperatures entering the heat exchanger for any given hour or day. However, the cold city water entering the system is fairly stable with only seasonal changes that roughly follow the average outdoor air temperature. The monthly cold water temperature can be estimated using data for heating degree days as a proxy for average outdoor temperature.

One estimate of average cold water inlet temp uses values developed by EPRI in TR-100212, Commercial Water Heating (Ref. 6) for various cities. Using a regression analysis for the Columbus, Ohio monthly inlet water temperature as a proxy of a mid latitude city, and monthly heating degree days (HDD) as an indicator of temperature, we are able to model the case for Baltimore as shown in the table A-1,1. (HDD is the annual heating degree days, base 65F).

Projected	Cold City Water temp, F from Regression calc using	Heating Degree Days	
	NOAA Baltimore & EPRI Columbus data	Baltimore	
JAN	38.0	1000	
FEB	44.5	816	
MAR	50.4	648	
APR	60.9	349	
MAY	69.0	120	
JUN	72.7	16	
JUL	73.2	0	
AUG	73.2	1	
SEP	71.8	42	
OCT	62.8	296	
NOV	53.1	570	
DEC	42.8	862	
Ave	59.4	4720	Total

Table A-1, 1 Baltimore Cold Water Temperatures

Using these water temperature values, along with the Typical Meteorological Year (TMY3) (Ref 5) solar and weather values, we can predict the expected water heating performance of the system throughout the year.

A graph of the predicted water and solar air temperatures into the heat exchanger is shown in Figure A-1, 11 for 6 'typical' days from July 3rd to July 9th. The data includes a prediction of the water and solar air temperatures into the heat exchanger using one and two solar fans. The case of one solar fan will be discussed later.

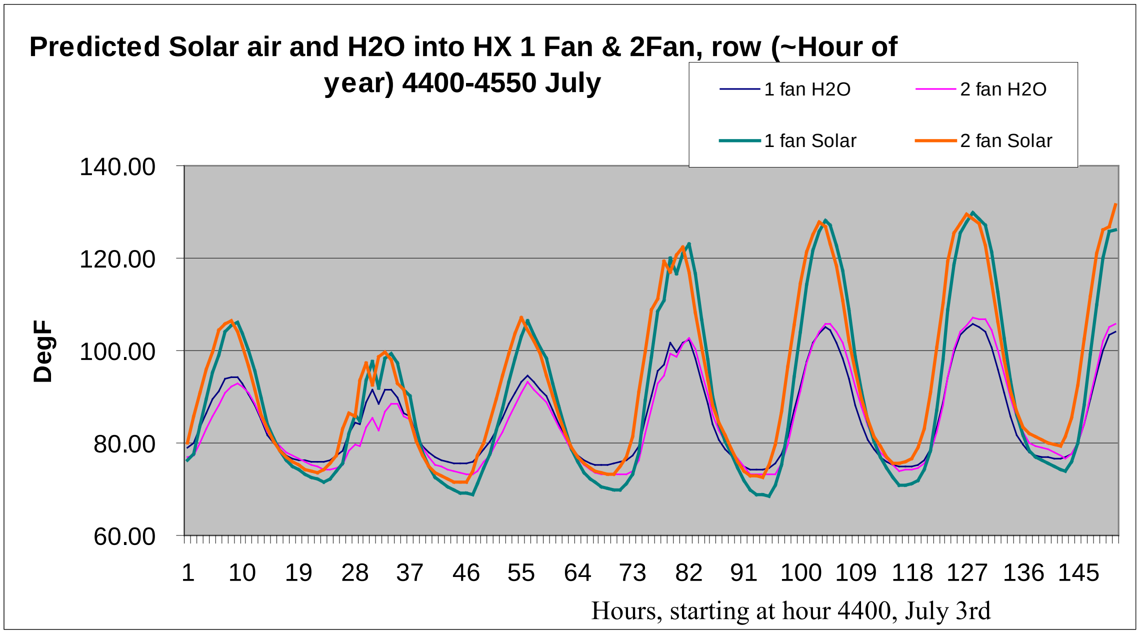


Figure A-1 , 11 Predicted Heat Exchanger Temps

Prediction of Solar Air Temperature

The prediction of solar air temperature into the heat exchanger is done in a similar manner to the prediction of water temperature into the heat exchanger.

Solar air temperature has been measured at several locations around the Gaffney solar roof. There is good agreement of the temperature readings at similar sensors in the roof and in the air to water heat exchanger. The chart in Figure A-1, 12, shows the solar air temperature entering the air to water heat exchanger (HX) during the ON hours from late June to July.

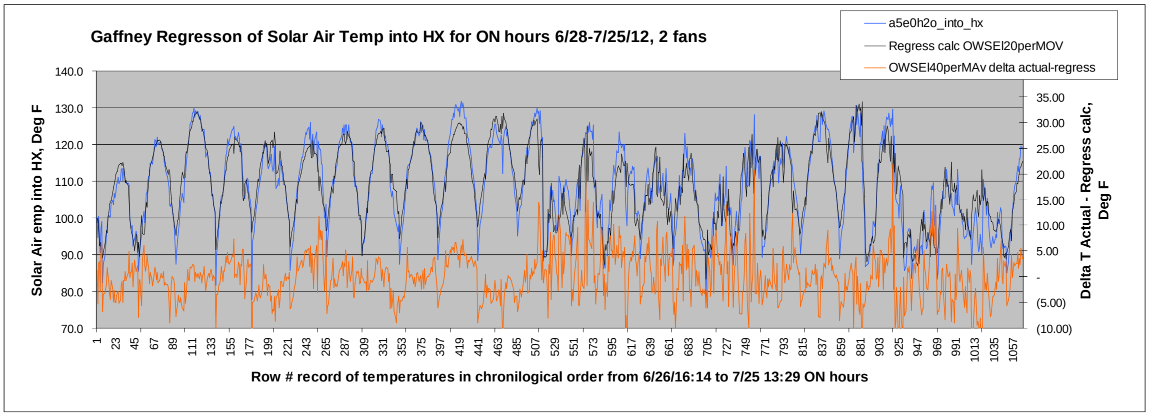


Figure A-1 , 12 Actual and Predicted Solar Temps

Several regression analyses were performed to develop a preferred model for the temperature of solar air entering the heat exchanger. The measured data used to model the solar air temperature include: the Outdoor Air Temperature (OAT), Average Wind Speed (Wind), Solar Insolation (SLR), and Solar Elevation (EL). Two derived values of 20 period moving averages for OAT (MAOAT) and SLR (MASLR) are also used.

The equation for prediction of solar air temperature is:

Solar Air Temp to HX = 13.5013 + 1.1338 * OAT + -0.1500 * Wind + 0.0302 * SLR + 0.0795 * EL + -0.1841 * MAOAT + -0.0110 * MASLR

Where: Solar Air Temp, Deg F; OAT, Deg F; Wind, MPH; Solar, W/M^2; Solar elevation, Deg above horizontal; MAOAT, Deg F; and MASLR, W/M^2

Figure A-1, 12 shows the modeled solar air temperature over the time period. It also shows the delta between the actual and modeled temperatures of solar air into the HX.

A review of the chart shows that the model generally agrees with the actual solar air temperature values. A closer review shows that the model tends to slightly under predict solar air temperatures at mid day and slightly over predict temperatures in the early morning and late evening. This is evident in the left half of the graph when days were generally sunny with minimal cloud cover. The 'delta' curve shows the low values in morning and evening and high values at mid day.

For the data shown on the right half of the graph, there was greater variability in the solar and weather conditions during many days (variably cloudy), which causes greater variability in any hourly prediction of the solar air temperature. A review of the detailed records showed that a passing cloud might drop the solar insolation from 600 to 250 W/SQ^M at the time of one 15 minute reading, but the thermal mass of the solar roof might help to maintain the solar air temperature through the period. This would result in a lower modeled temperature than the actual solar air temperature measured.

While the overall fit of the model is a good representation of the actual data over daily, weekly, and monthly periods, the model does not have the precision to accurately predict solar air temperature for each and every individual 15 minute period.

Prediction of Turn ON and Turn OFF times

One additional value to be extracted from the Gaffney data is the expected temperature when the solar fans and pumps Turn ON and Turn OFF. The differential controller is set to turn the fans on when the solar roof temperature is 8 degrees warmer than the top of the preheat tank and turn it OFF when the solar air drops to less than 4F warmer than the preheat tank. However, the Turn ON and Turn OFF temperature generally correlate with the Outdoor Air Temperature, OAT, permitting the use of OAT to predict ON & OFF times.

The Gaffney data in Figure A-1-13 showed that the average calculated solar air temperature was 13.1F warmer than the outdoor air temperature when the solar fans 1 & 2 turned ON. The average calculated solar air temperature was 15.6 F warmer than the outdoor air temperature when the solar fans turned OFF. (Note that the actual Turn ON, Turn OFF temperatures are closer to the Differential temperature settings of 8F &4F, but the model calculation was used here for consistency in predicting ON-OFF using OAT from the TMY data.) Using these values we can predict the hours during the year when the solar fans and pump will be ON and running to preheat hot water. A review of the 8760 hours, predicting solar air temperature using the regression equation above and the TMY3 outdoor air temperature data for Baltimore indicates that the system will run in hot water preheat mode for 3,025 hours per year, or 35% of all hours of the year.

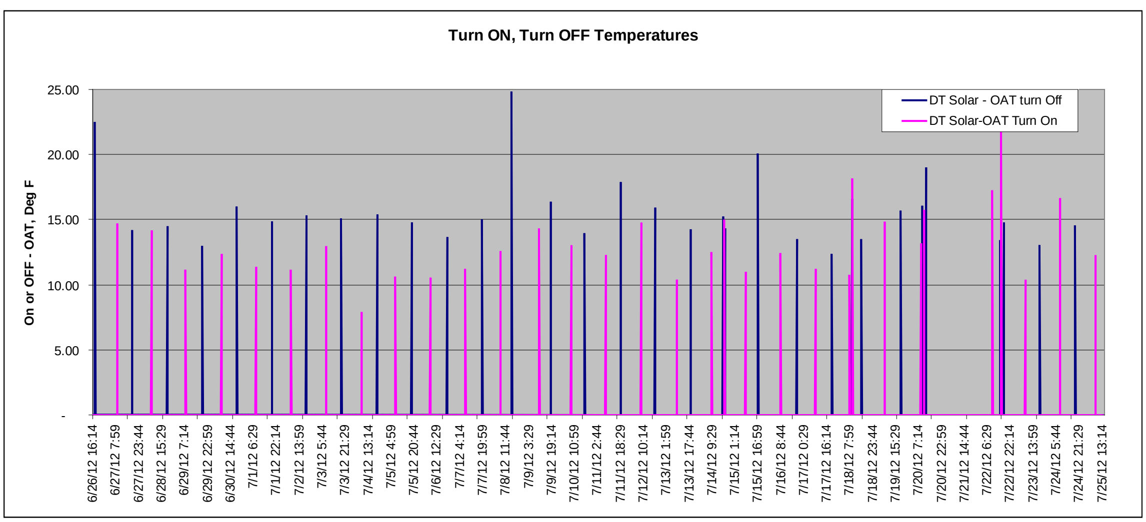


Figure A-1 , 13 Actual Turn ON-OFF Temps

Prediction of water temperature into the heat exchanger

A regression analysis of the water temperature into the heat exchanger during ON hours based on the same parameters provides the equation:

Water Temperature to HX = 4.1266 + 0.9008 * OAT + -0.0302 * Wind + 0.0179 * SLR + -0.0027 *EL + 0.3177 * Cold City H2O + -0.1525 * MAOAT + -0.0200 * MASLR

Where: Water Temperature, Deg F; OAT, Deg F; Wind, MPH; Solar, W/M^2; Solar elevation, Deg. above horizontal; Cold City H2O, Deg F; MAOAT, Deg F; and MASLR, W/M^2

Prediction of Heat transfer from air to water

The air to water heat transfer in the heat exchanger can be modeled using the difference between the solar air temperature and the water temperature into the heat exchanger. During the July test period, the average temperature difference between the solar air and water entering the heat exchanger was 11.4F. During the July test period the average heat transfer was 1,142 BTU/Hr/ DegF delta solar air –water to HX.

A plot is shown A-1, 14 below of the calculated heat transfer in the heat exchanger vs. temperature difference (Delta T) between solar air and water entering the heat exchanger along with the modeled trend line and equation.

The spread of values at the lower temperature is an indication of the affect of heated water returning from the preheat tank and varying cold water flow into the system with varying hot water demand. As the delta T in the heat exchanger drops, the heat transfer in the heat exchanger decreases leading to larger variations in the 'modeled' BTU/HR/Delta T due to influences of stored return water and hot water demand. However, the trend in BTU/HR/Delta T is clear and useful in predicting heat transfer during given months as the Delta T changes through the year.

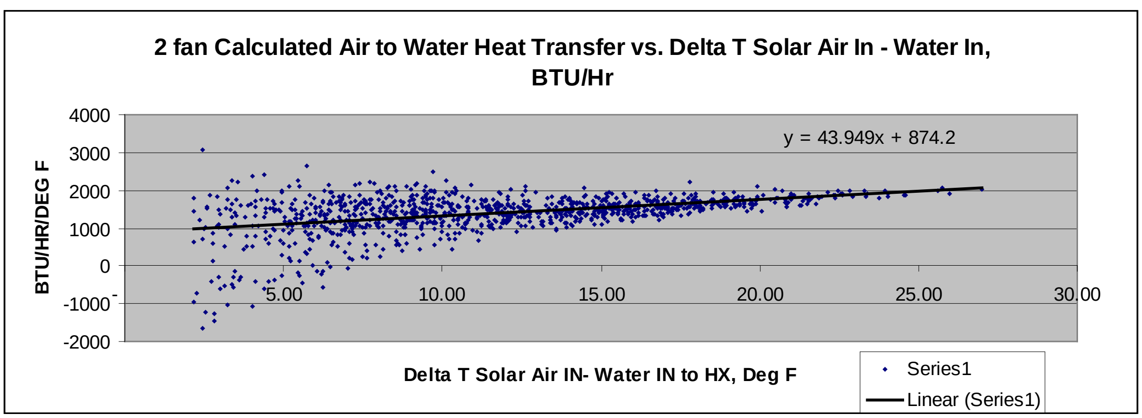


Figure A-1 , 14 2-Fan Heat Transfer vs DT

Using the model equation above and TMY3 data, there are 2835 ON hours per year. The average heat transfer from air to water for each ON hour is 13,051 BTU/HR for a total of 51.6 million BTU/yr. From April to October the heat transfer it 38.9 million BTU.

The solar air for the heat exchanger is drawn from 3 roof zones; zone 1, 2, and 5 in the roof plan Fig. A-1, 15. The total area of the 3 roof zones is 3,955 square feet. We can divide the heat transfer by the square feet of roof from which the air is drawn and develop a value for BTU/square foot per year. By this simple metric the Gaffney water heating system delivers 13,051 BTU/sqft/year for water preheating, or 1,088 BTU/sqft/month, with a calculated peak heat transfer of 12 BTU/sqft/hr. During the 7 months from April to October, the system delivers 38.9 million, 9,832 BTU/sqft/7 months or 1,405 BTU/sqft/month.

Underestimating Solar Heat Transfer /square foot

The simple metrics for BTU/sqft above underestimate the maximum heating capability of the solar roof on the Gaffney building. The reason is that the solar roof areas used are larger than needed to provide adequate air flow for the heat exchanger. The large areas used in the denominator reduce the BTU/sqft values beyond those necessary to produce the same BTUs of heat transfer with a smaller square footage of roof.

The large areas of the roof are part of the overall design to install a solar roof on the southwest slope of the building for roofing, space heating, and water heating. As part of the re-roofing, the roof needed to be divided up into zones, for fire protection purposes. See Figure A-1, 15. The division of those zones took account of the roof dividing structure, the maximum area allowed for each zone (3,000 square feet) and the solar air flow paths and areas to balance the pressure drops to the solar fans.

Zone 1, 1,240 square feet, and zone 2, 1,155 square feet are roughly equal in area and supply a roof air plenum that exhausts into a 20 inch diameter duct with a measured 2 fan air flow 2,898 cubic feet per minute (cfm), or 1.21 cfm/sqft. Zone 5 is 1,560 square feet and supplies a plenum with 6 inch diameter outlet and measured 2 fan air flow of 420 cfm, or 0.27 cfm/sqft. The totals for the heat exchanger are 3,955 sqft and 3,318 cfm, or 0.84 cfm/sqft. Despite the difference in flow rate/ per square foot between the sections there was no measured difference in temperature between the 20 inch duct and the 6 inch duct operating at different flow rates.

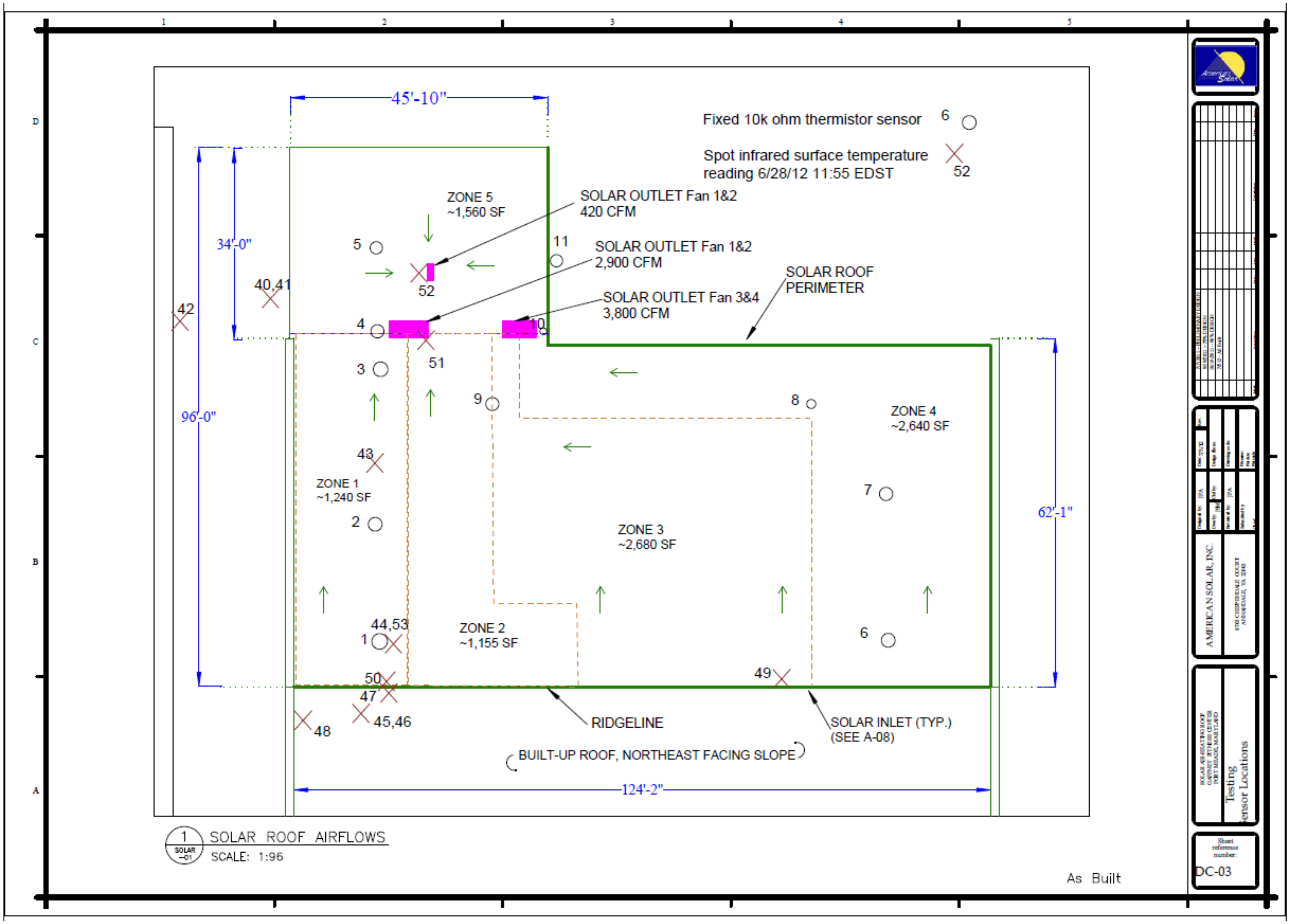
There are several reasons why the solar temperatures do not vary given the variation in roof areas supplying the different air paths. First, the runs of solar air from the inlets to the roof plenum are up to 60 feet long in zones 1 & 2 and up to 20 feet long in zone 5. For solar heating purposes, the run of outside air through the solar roof to the plenum needs to only be about 15 feet to achieve a full, expected temperature rise. Second, the Gaffney data for the roof temperatures show a relatively stable solar air temperature in the roof from high spots near the inlets, to mid levels, to low spots near the outlets. This indicates that the solar air is becoming fully heated well before it reaches the outlet plenums. Third, infrared spot temperatures of the exterior of the roof panel, measured at various spots down the slope of the roof show a consistent roof panel temperature, indicating that the roof has reached a stable temperature, with air flow beneath the panel no longer extracting heat and cooling the panel. Fourth, there is no temperature difference between the solar air temperature from zones 1&2 and zone 5 which have different air flow path lengths and cfm/sqft flow rates.

From this evidence, we can conclude that several feet of the existing air flow paths are not contributing to any additional heating of the solar air. Conversely, we can conclude that shorter solar air path lengths (i.e. less area) could provide equivalent temperature rise with the same volume flow. Therefore, the area required to deliver the same heating could be much smaller than the 3,955 square feet currently attributed to the air to water heat exchanger in these calculations.

A second reason the heat transfer capability of the solar roof is underestimated at the Gaffney Building is that the variable and low demand for solar preheated water results in a high preheat storage temperature and low heat transfer in the heat exchanger. This is discussed in detail later in the section entitled "Maximum Water Heating Capacity".

The sizing of the installed system, is adequate for the irregular demand, with solar heat being stored in the preheat tank when there is no demand. This causes the preheated water that is supplied to the heat exchanger to rise to close to the solar air temperature, which reduces heat transfer in the heat exchanger. If instead, the heat exchanger were supplied with cold water all day, the system would operate 306 more hours per year and the heat transfer during all hours would be greater. The capacity of the installed systems would be 213.4 million BTU/year, and 4,496 BTU/sqft/mo and calculated peak heat transfer would be 64 BTU/sqft/hr. This is essentially 4 to 5 times larger than the heat transfer met by the as built system to satisfy the Gaffney buildings variable and low flow.

Figure A-1, 15 Sensor Location Plan



One Fan Operation
The initial testing in July, was done with solar fans 1&2 running to supply solar air to the heat exchanger.

However, the system is set up so that it can be run with just 1 fan supplying the heat exchanger. This reduces the electric load, by 45% to 1637 Watts, 5587 BTU/hr equivalent. Air flow measurements on the ducts to and from the heat exchanger show that the air flow across the heat exchanger was reduced by 42%, from 3320 cfm to 1918 cfm. There is no noticeable change in solar air temperature from the change in air flow.

On August 15th, the system was set to run on one fan supplying the heat exchanger. For the first week, through 8/21, the pump was set to run continuously and the fan only turned ON whenever the solar air temperature was 8F hotter than the top of the preheat tank and OFF when less than 4F than the top of the preheat tank. From 8/21 to 9/2, the pump was set to run only when the fan ran.

Figure A-1,16 shows ALL hours of a four day period. Temperature curves of solar air and water into and out of the heat exchanger, and temperature changes through the heat exchanger, along with fan operating hours, and outdoor air temperatures. In general this shows similar performance to the 2-Fan case with peak solar air ~40F above outdoor air and peak water temperatures consistently 25F above outdoor air temperatures.

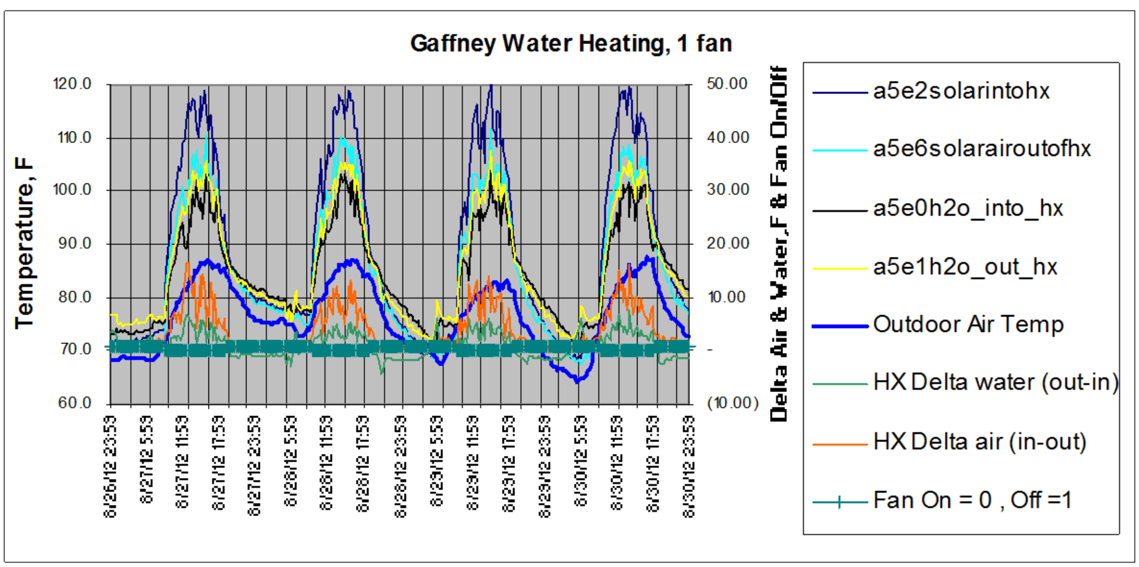


Figure A-1 , 16 4-Day Water Heating Temps

Figure A-1, 17 shows the performance of the solar water heating system during ON hours only, over a 4 day period, using 1 fan. The graph also shows plots of predicted solar air temperatures in the roof and into the heat exchanger, using similar regression analysis techniques described above for 2 fans.

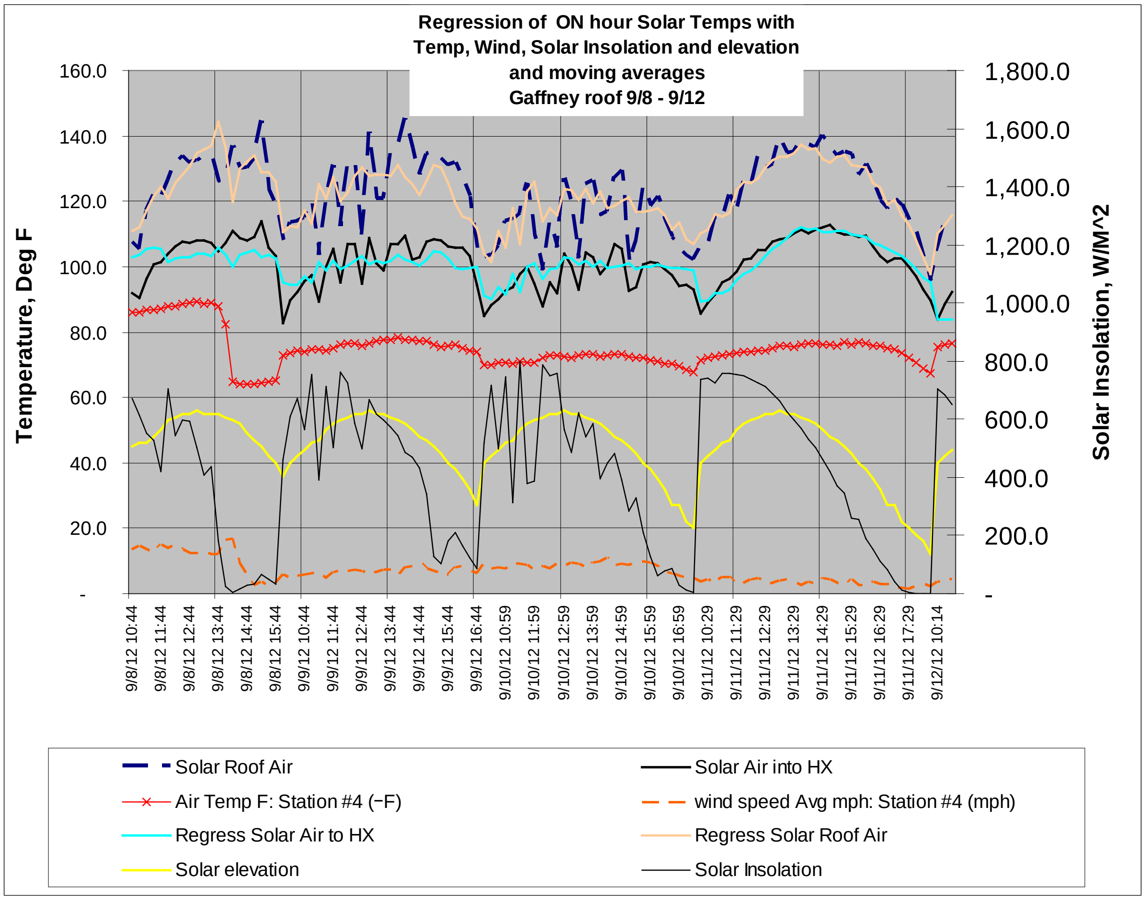


Figure A-1 , 17 Regression ON Hour Solar Temps

A similar regression analysis to the 2 fan case provided a similar predictive equation for the temperature of solar air entering the air to water heat exchanger. Figure A-1, 18 below shows the actual and predicted (Regress calc…) solar air temperature into the air to water heat exchanger using the measured data for outdoor air temperature, solar insolation and elevation, and wind speed.

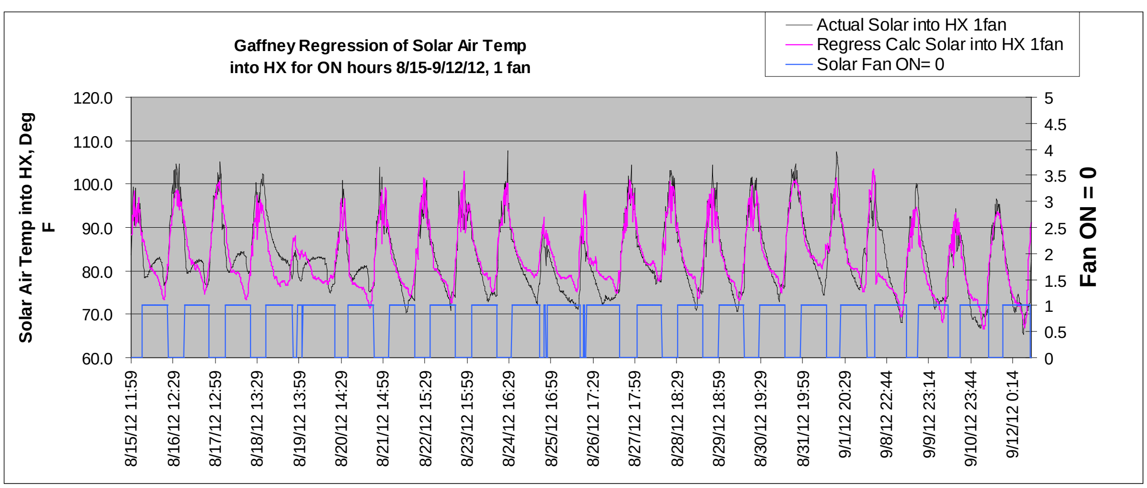


Figure A-1 , 18 Predicted and Actual Solar Temps

Figure A-1, 19 shows the prediction of solar air and water temperatures entering the air to water heat exchanger for the first 2,000 hours of a typical meteorological the year.

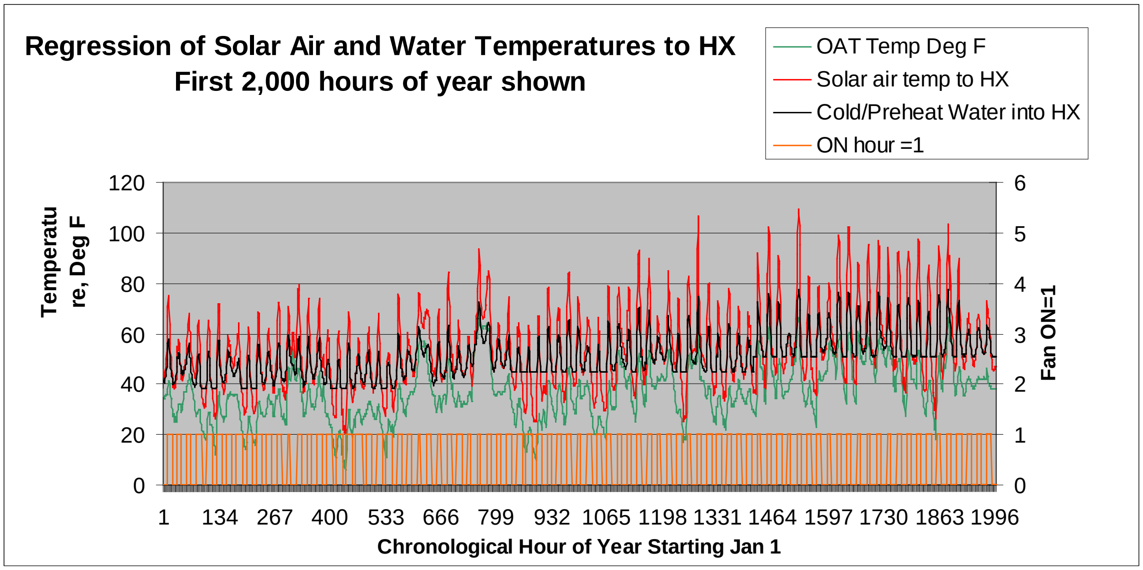


Figure A-1 , 19 Regression Solar Air and H2O Temps

With one fan running, the maximum <u>measured</u> heat transfer at the Gaffney building from Aug. 16 to Sept. 12 was 31,189 BTU/hr. The average over the ON hours was 16,406 BTU/hr. The average temperature difference between solar air into the heat exchanger and water into the heat exchanger is 11.9F. Average BTU/Hr/ DegF DeltaT Solar air-H2O to HX is 1029. See Figure A-1, 20

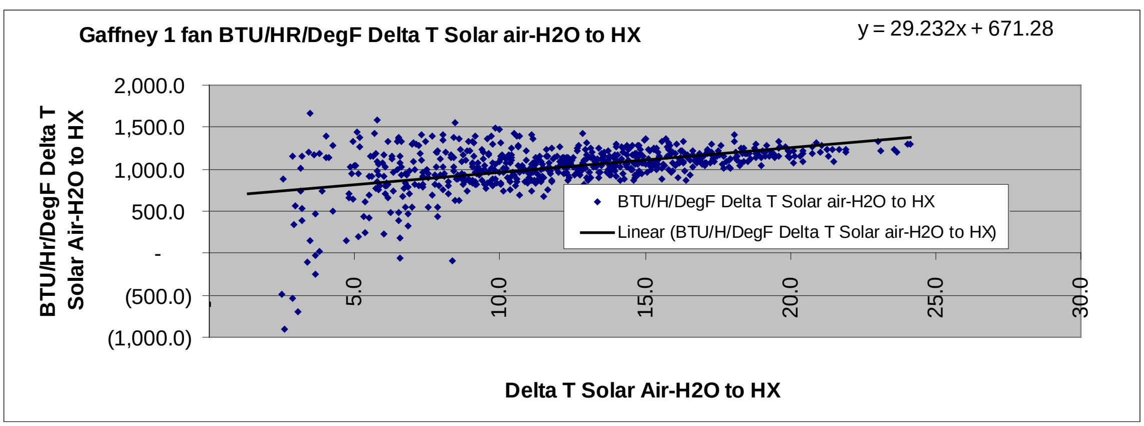


Figure A-1 , 20 1-Fan Heat Transfer vs. DT

Using the regression analysis approach, annual heat transfer from solar air to water in the heat exchanger is 47.7 million BTU/yr, with 3,025 operating hours per year. This is 92% of the heat transfer and 7% more hours of operation that the 2 fan case.

<u>Electrical energy use, 1 Fan case</u>

During the August – September tests with 1 fan, the system operated with solar fan 1 only through 9/2, and with solar fan 2 only through 9/12, and the solar pump running all days. Each solar fan draws 12.01 amps at 114 VAC, or 1369 watts. The solar pump is rated at 1/3 horsepower, or 248 watts. Power for the control systems is less than 20 watts. So total power for 1 fan operation is 1637 watts, or 5,587 BTU equivalent.

The average hourly heat transfer over August 27 was 15,985 BTU/hr. So, the solar heating system delivered 2.9 times as much heat energy as the equivalent electrical energy consumed to run the system. During the peak operating hour, at 12:30, the system delivered an average heat transfer of 28,814 BTU/hr. During that peak hour the system delivered 5.2 times as much heat energy as the electricity consumed.

When a full year of operation is calculated using the regression analyses and TMY3 information, the one fan systems heats water with an average of 2.82 times the energy used to run the fans.

<u>Variability in the modeling of heat transfer between 1 fan and 2 fan operation.</u>
As mentioned above, using the regression analysis approach, for the 1 fan case, annual heat transfer from solar air to water in the heat exchanger is 47.7 million BTU/yr, with 3025 operating hours per year. This is 92% of the heat transfer and 7% more hours of operation that the 2 fan case.

Although a quick first estimate might suggest that half the fan power would result in half the heat transfer, there are several real and calculated elements at work to support the predictions.

One reason is the fact that cutting fan power in half lowers air flow but only in accordance with the balance of the air pressure drop of the system. So, 2 fans supply, 3,320 cfm of solar air while 1 fan supplies 1,918 cfm, or 58% of the air for 2 fans.

One reason for the slightly lower predicted heat transfer and higher hours can be seen from graphs of the solar air and water temperatures for the 1 fan and 2 fan cases at different times of the year. See Figure A-1, 21. While the models are consistent during the summer months, as shown in the graph below, they diverge in the winter months.

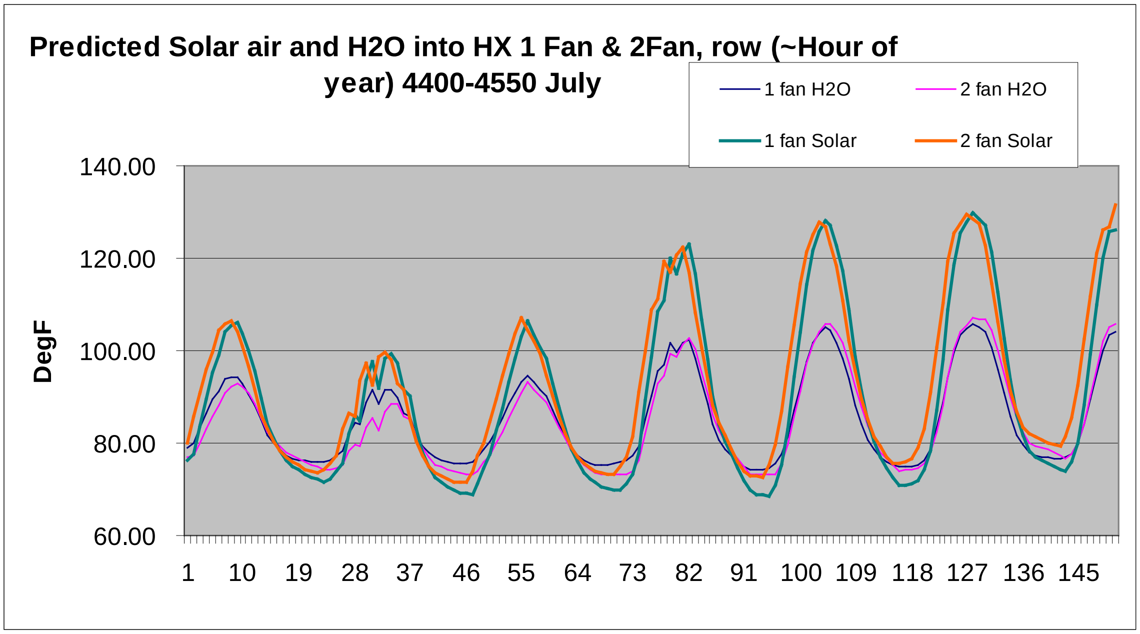


Figure A-1 , 21 1&2 Fan Solar & H2O Temps July

Specifically, the model for the 1 fan case shows higher solar and lower water temperatures in the winter than the 2 fan case. The difference between solar and water temperatures is also greater for the 1 fan case vs. the 2 fan case. This leads to more ON hours for the 1 fan case and higher heat transfer in the heat exchanger during those hours. In Figure A-1, 22, the predicted temperature of the solar air in the 1 fan case is higher than the solar air in the 2 fan case. Similarly, the water entering the heat exchanger is only slightly lower for the 2 fan case. The delta between solar air and water affects the TURN ON and TURN OFF timing of the systems, predicting more ON hours for the 1 fan case.

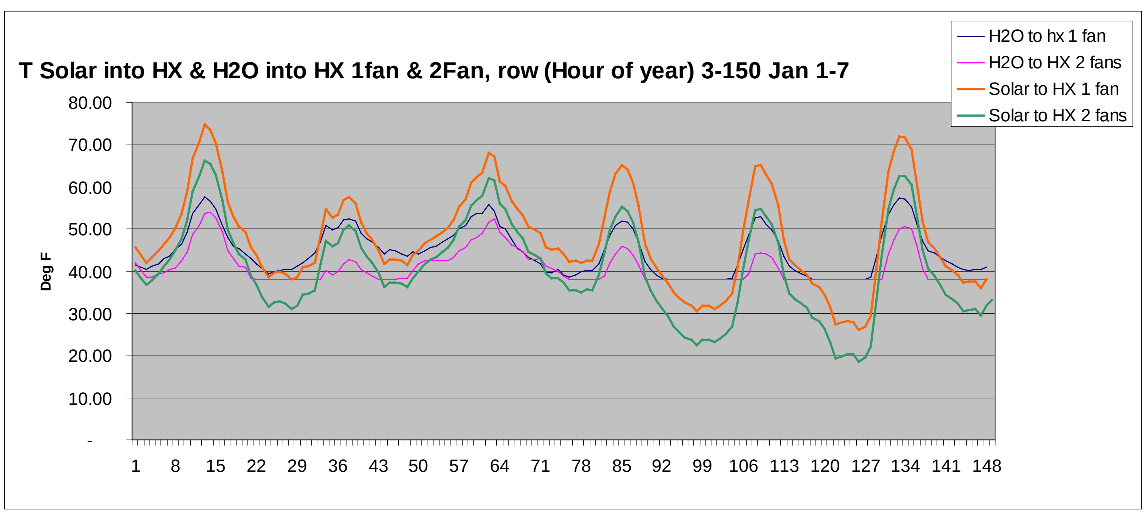


Figure A-1 , 22 1&2 Fan Solar Temps January

The difference it thought to be a result of several minor variations in the regression analyses caused by weather, and the variability of the basic regression analysis technique.

1. The weather conditions during the data collected for the 2 fan case were consistently hot and sunny. For the 1 fan case, the weather started hot and sunny but shifted to cooler and partly cloudy days. While the summer predictions for both the 1 fan and 2 fan cases are very consistent, the slight change in weather likely contributes to a variation in predicted winter performance. Longer data collection periods for both the 1 fan and 2 fan cases would be expected to result in greater consistency in the winter months.
2. The Turn ON, Turn OFF temperatures are predicted based on the average of measured data for the difference between the solar air temperature to the heat exchanger and the outdoor air temperature (OAT) when the system Turns ON and Turns OFF. Table A-1, 2 shows the average Turn ON, Turn OFF temperature differences for the 1 and 2 fan cases. When applied to the prediction of annual performance, these temperature differences are calculated between the 'predicted solar air temperature to the heat exchanger' and the outside air temperature from the TMY3 data. The slight variation in the predicted vs. actual solar air temperature can cause a variation in operating hours.

	Turn ON Delta T (Solar air to HX – OAT)	Turn OFF Delta T
2 fans	13.1 F	15.6 F
1 fan	15.4 F	14.0 F

Table A-1, 2 Turn ON-OFF Temps

It is believed that additional data collection over a longer period of time, with greater outdoor air temperature variation will result in a better model of the one fan and two fan cases.

For the Gaffney Fitness Center, with variable water flow during the day, and an excess of solar heating capacity from the large roof, use of one fan is the preferred alternative. The analysis above shows one example of how the factors are analyzed for this case and should be analyzed for other projects with different utility rates and water use, Maximum water heating capacity

The heat transfer in the air to water heat exchanger varies throughout the day with the changes in incoming solar air and incoming water temperatures. That variation in heat transfer can be closely predicted by the difference in temperature between the incoming solar air and incoming water at the heat exchanger. Figures A-1, 23 and 24 show the heat transfer in BTU/Hr/Deg F(Delta T Solar air – H2O to the HX) for the 2 fan and 1 fan cases.

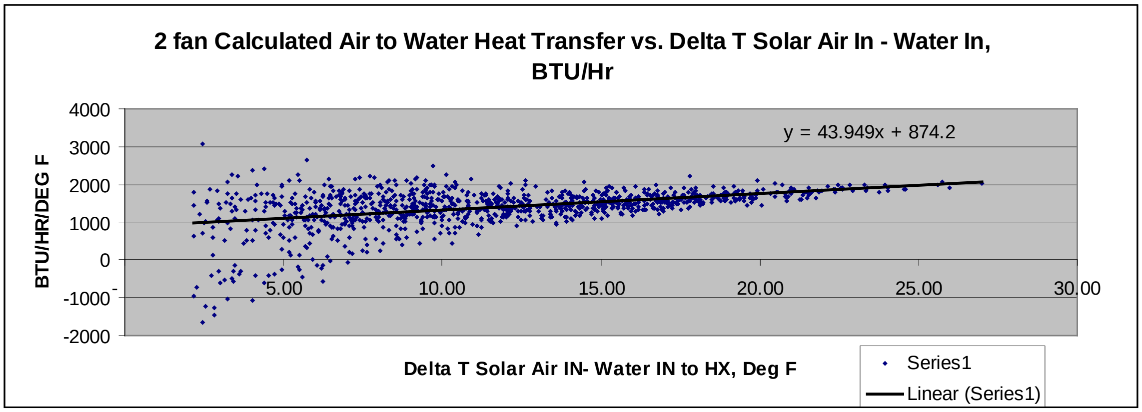


Figure A-1 , 23 2-Fan Heat Transfer vs. DT

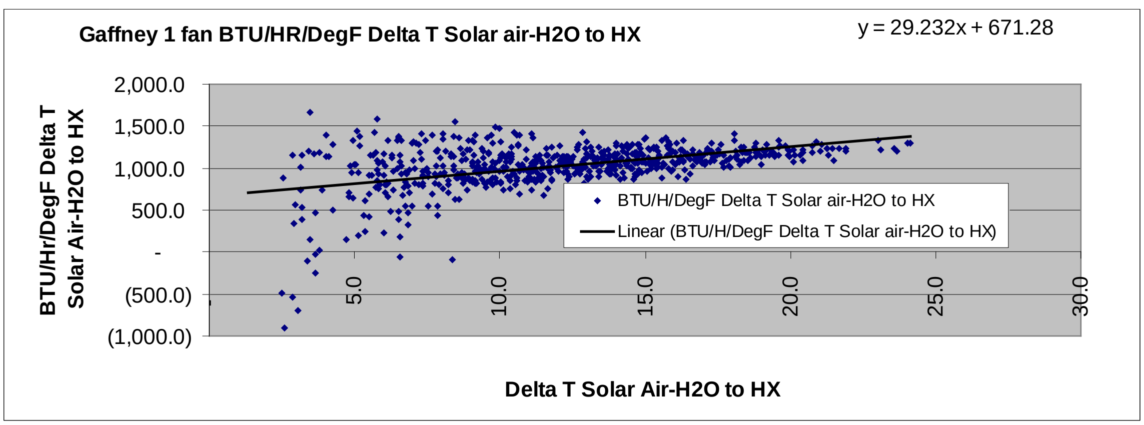


Figure A-1, 24 1-Fan Heat Transfer vs. DT

The existing system operated with a Delta T between solar air and water from 0 to 26.6F for the 2 fan case in June and July, and from 0 to 24.1F for the 1 fan case during Aug. and Sept. (For clarity in plotting, data points below ~2.5 are not shown.) Over the testing period, the Delta T for the 2 fan case averaged 11.4F with an average heat transfer of 16,866 BTU/hr. For the 1 fan case, the Delta T averaged 11.8F with and average heat transfer of 12,684 BTU/hr.

The air to water heat exchanger coil was designed with these expected flows and with a range of temperatures for incoming solar air and 'cold' water. The peak design point for the coil was 3,800 cfm of solar air at 130F, and 10 gpm of entering water at 60F, with a

Delta T of 70F between entering solar air and water. Under those conditions, the coil will deliver 180,000 BTU/hr of solar heat from the air to the water.

The initial testing measured 3,320 cfm for 2 fans and calculated 11.3 gpm of water flow, which is well within the design capacity for air and water flow. However, the variability of hot water demand in the building, causes temporary daily heating of the water in the preheat loop and tank, which raises the water temperature returning to the coil and keeps the Delta T lower than the peak design point. While this is the appropriate way to design the system, the average Delta Ts and heat transfer values do not give an indication of the maximum capacity of the system.

To predict that maximum capacity, we can compare the case where the water entering the heat exchanger is only the cold city water, with no prior preheating from the solar reheat system. This would represent a case of a building with a high water demand so that all the preheated water was constantly being consumed.

Using the values for predicted solar air temperatures and the cold city water temperature, and the BTU/HR/DegF(deltaT) equations from the graphs above, we can predict that heat transfer for each hour of a typical meteorological year. For the 2 fan case the predicted peak hour heat transfer is 252,781 Btu/hr. In the typical meteorological year, this occurs on a warm, 91F May day with water temperatures of 69 F. The predicted solar air temperature would be 136F resulting in a Delta T of 67F.

Annually, the system would deliver 213.4 million BTU, 5 times more heat transfer than is predicted for the existing 'as built' operations, which return preheated water to the coil instead of cold water. Using the total area of solar roof, of 3,955 square feet, the maximum heat transfer would be 53,855 BTU/sqft/yr with a peak heat transfer of 64 BTU/sqft/hr.

For the 1 fan case, the maximum heat transfer predicted is 187,608 BTU/hr. This is predicted to occur on a typical day in early May with a solar air temperature of 135F and a water temperature of 69F and a Delta T of 66F.

Annually, the 1 fan system would produce 159 million BTU, 3.3 times more heat transfer than is predicted for the existing operations, which return preheated water to the coil instead of cold water. Using the total area of solar roof, of 3,955 square feet, the maximum heat transfer would be 40,202 BTU/sqft/yr with a peak heat transfer of 47 BTU/sqft/hr.

Economic Considerations

The Gaffney Fitness Facility currently heat domestic hot water using a new condensing gas boiler, the manufacturer's data shows that the boiler is about 90% efficient when heating the 130F water in the domestic water loop. Gas prices in July 2012 were $0.87 per therm ($8.70/million BTU). For a 90% efficient boiler, this means hot water is produced and delivered to the building loop at $9.70 per million BTU.

If the “as built and operated ” hot water heating systems uses 1 fan, it produces 47.7 million BTU/yr at Gaffney, saving $461 per year. Electric costs, to run the fan and pump, at $0.115/kwhr and 3025 hours and 1637 watts are $584 per year, for a net negative of $121 per year. If the system operated at “maximum energy” delivery (i.e., constant cold water supply) with 1 fan it would have delivered 159 million BTU/year at a net cost savings of $953 per year.

With the 2 fan case, the Gaffney system produces 51.6 million BTU/yr of heat for the hot water system, saving 57.3 million BTU and $499 in natural gas. The electric cost would be $1,006 per year, for a net negative of $507 per year. If the system operated at maximum energy delivery (i.e., constant cold water supply) with 2 fans it would have delivered 213 million BTU/year to the water, saving 237 million BTU in gas and $2,063, for a net savings of $1,057 per year.

The negative savings values for the current installation are primarily a function of the variable water flow demand from the gym and the thermostatic controller settings. Based on the calculations of water flow described above, the solar preheat system delivered a variable flow to the building of between 0 and 4.1 gallons per minute on July 6th. The variability is driven by the demand for hot water from the sinks and showers, which each draw about 2.5 gallons per minute. The 2 inch diameter city cold water pipe feeding the hot water boiler indicates the existing boiler based hot water system is capable of about 45 gallons per minute of peak cold water flow, roughly 20 simultaneous showers and sinks.

There are three ways to improve the solar water heating performance of the existing system; 1) increase cold water flow through the preheat system, 2) install a smaller fan and pump, and 3) reduce fan and pump operating times. A fourth option of increasing storage volume to keep preheat temperatures down and increase heat transfer across the heat exchanger would offer little help since the storage volume is well matched to the demands of the day, with preheated water being nearly fully spent by the end of the day. A larger storage system, with about 8 times higher cost per gallon, would heat up over a few days to a high temperature, eventually reducing heat transfer in the heat exchanger.

Option 1, increased cold water flow could be accomplished by forcing more water through the preheat system and less though the parallel cold water inlet to the boiler. This could be accomplished by partially closing a cold water valve in the boiler inlet line. The partial closure would need to maintain the total peak capacity of the combined system at 45 gpm, with ideally 10 gpm of preheat water and a peak of 35 gpm of cold water to the boiler. This would keep preheat temperatures lower, increasing heat transfer at the heat exchanger and increasing preheated water into the boiler.

Option 2, installs a smaller fan and pump to reduce electricity use. This results in a reduction in solar heat transferred to the building, but it improves the BTU/kwhr ratio. This is similar to the benefits seen in switching from 2 fans to 1 fan, which showed an increase of from 6,728 BTU/kwhr (2fans) to 10,703 BTU/kwhr (1fan).

Option 3, reduce fan and pump operating times is the preferred option. It involves simply changing the thermostatic setting on the differential controller to start and stop the solar fan and pump at a higher temperature difference between the solar air and the preheat tank. This will have the effect of reducing the total heat transfer to the building, by lowering the preheat tank temperature, which increases heat transfer in the heat exchanger, but over fewer operating hours. This should be accomplished by adjusting the TURN ON differential setting of the differential thermostat and by inserting a fixed electrical resistance in series with the solar roof thermistor sensor. The higher TURN ON setting of the differential thermostat will delay the start of the fan and pump. The artificially higher resistance in the solar roof thermistor circuit sensed by the differential thermostat indicates a cooler roof temperature and will hasten TURN OFF of the solar fan before the normal controller TURN OFF temperature difference of 4 degrees F. With more time OFF, there will be less continuous heating of the preheat tank, permitting cold water to enter the tank, keeping the preheat tank temperature lower.

A review of the breakeven energy delivery for the Gaffney arrangement shows that the 1 fan case costs $0.19 per hour to run the fan and pump. With natural gas heating at $9.70 per million BTU delivered to the water, there must be a solar heat transfer to water of 20,000 BTU/hr to breakeven with electric costs. This heat transfer rate occurs when there is a temperature differential of 19 degrees F between solar air and water entering the heat exchanger. So, setting the TURN ON differential to 20F and inserting a fixed resistance of 1800 ohms in series with the solar roof sensor, will cause the systems to TURN ON and OFF only when the energy cost savings will be positive.

This will keep the preheat tank cooler by shutting off the fan temporarily when the preheat water temperature comes within 20F of the solar air temperature and allowing more time when cold water will enter the preheat tank before the fan and pump start again. This will increase heat transfer across the heat exchanger for fewer operating hours. The adjustments will be made during the spring of 2013, after the conclusion of this ESTCP project.

While this ESTCP project has (for the first time) provided the means to accurately estimate the solar air and preheat water temperatures and heat transfers, a rigorous simulation of the savings using this Option 3 approach are beyond the scope of this ESTCP project. Such a simulation would require hour by hour estimates of ON/OFF hours, heat transfer in the heat exchanger, preheat tank temperature, and building demand. This was not intended as part of the ESTCP project, but the data and modeling now exist to accurately make such a prediction, given the time and effort.

However, a quick review of the existing annual hourly heat transfer model indicates that the system, using Option 3, would likely operate for ~1,200 hours per year. During those operating hours it is expected that the solar hot water heating savings would total about 41 million BTU/yr. This is roughly 40% of the current operating hours, but delivers about 86% of the current one fan energy savings. This is because all unproductive hours, below 20,000 BTU/hour to the water, are eliminated and there is greater production per hour

(BTU/kwhr) due to the higher temperature difference across the heat exchanger. This would save about $401 in gas heating and cost $241 in electricity, with a net savings of about $160 per year for the specific arrangement at Gaffney.

Summary

The Gaffney Fitness Center domestic hot water preheat systems has demonstrated and documented several aspects of the solar roof air to water heating system.

First the data collected have permitted the validation of a "first ever" numerical model of an unglazed solar air heating roof system. The model permits calculation of expected solar air temperature, and solar preheated water temperature for any location using typical meteorological year weather and solar data.

Second, the model has permitted the calculation of annual capacity of the system to deliver solar preheated water and maximum deliverable capacity of the solar air to water heating systems for the specific arrangement at the Gaffney Center.

Third, the testing has shown that there is considerable additional heating capacity in the Gaffney solar roof beyond that required for domestic hot water heating. Roof temperatures show that there is little cooling of the solar air and roof panels beyond a short distance from the air intakes. This indicates that either greater air flow through the existing outlets, or from more widely distributed outlets would increase the total heat extracted.

Fourth, the widely varying hourly water demand in the building creates a challenge to maintaining high heat transfer from the solar air to water heat exchanger. This is due to rapid heating of the water in the preheat tank when there is minimal hot water demand in the building, which reduces heat transfer in the solar air to water heat exchanger. Proper adjustment of the thermostatic controls can partially overcome any negative impacts to ensure positive net energy and cost savings.

Fifth, with current electrical and natural gas costs and the use of an efficient condensing gas boiler, the system must produce ~20,000 BTU/hour to breakeven from gas savings and electricity operating expenses. If the systems operates at all hours when it can deliver gas savings, regardless of the electric cost, the systems deliver ~53 million BTU in gas savings but costs ~$120/year more than it saves. If the system is operated during only those hours when it contributes positive cost savings, it is projected to deliver 41 million BTU and save $160 per year.

Fifth, the modeling of the system installed at Gaffney has shown that the system has a much greater capacity to deliver energy than is required by the current arrangement. If the system is installed, and operated so that all water entering the heat exchanger is cold city water, then the system can deliver 215 million BTU/year at a net cost savings of around $1,050 per year.

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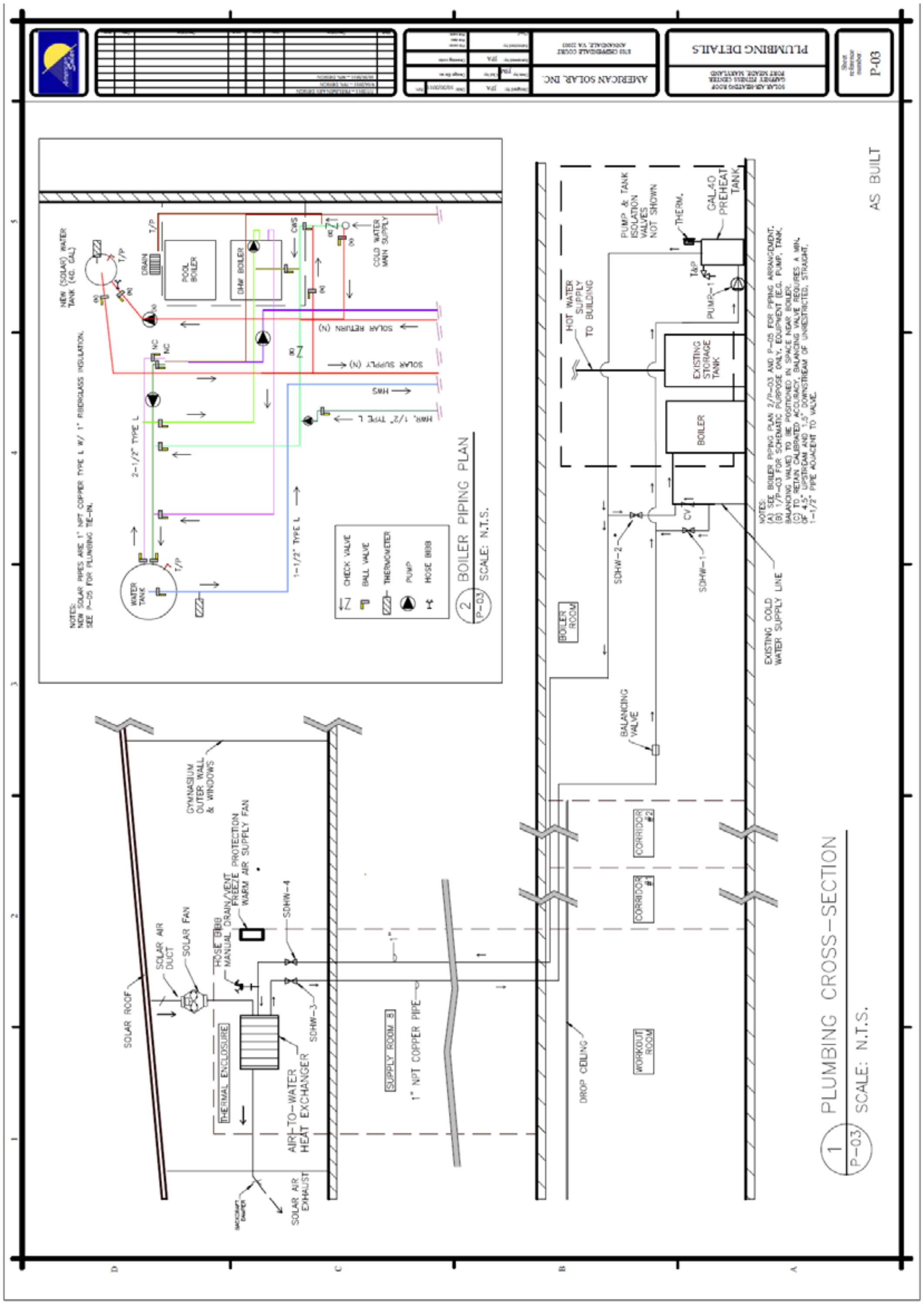


Figure A-1, 254 Solar Plumbing Arrangement

Extended List of Findings and Results:

For many facility managers and design professionals, a snapshot of results and performance of one project is helpful in understanding the scope of the project and approaching the design of a new system. Toward that end, the following is a list of findings and results from the Gaffney Fitness Center Solar Air Heating Re-roof that will help the reader to quickly get a sense of the scope, performance, and economics of the solar air to water heating system.

The Solar Air Heating Roof and Air to Water Heat Exchanger:

1. <u>Delivered an average of 2 gallons per minute of preheated water to the building.</u>
2. During July, the peak solar preheat temperature for water returning to the building was 124.4F with cold city water entering at 82.7F and the building conventional hot water system circulating hot water at 130F
3. During July, the peak water heating capability recorded was 31,700 BTU/hr
4. During July, the system provided an average of 125,000 BTU per day of solar preheat to the cold water intake of the building hot water heating system.
5. In July, the solar preheated water returning to the building averaged 93.3 F, when the cold city water averaged 78.2F.
6. In July, the preheat water temperature returning to the building reached a maximum of 46F hotter than the cold city water.
7. During July, the system delivered solar heated water to the building for an average of 11.75 hours per day, with fans and pump operating 9.25 hours per day and heat from daily storage providing 2.5 additional hours of heat.
8. The solar air exhausted from the air to water heat exchanger averages only 5.2 degrees F colder than the solar air into the heat exchanger, indicating that there is a substantial opportunity to use the solar exhaust air for other heating uses including space heating in the spring and fall.
9. The installed solar air to water heat transfer system is capable of providing much more heat/square foot of solar roof than was required to meet the hot water load in the Gaffney Building. The actual recorded heat transfer of the installed systems per square foot of roof is approximately 30% of the maximum installed heating capacity due to the use of a much larger area of the roof, which was installed for roofing purposes and available, but not necessary, for the small water heating load.
10. During July, the peak measured heat transfer in the air to water heat exchanger was 13.9 BTU/sqft/hr. With a larger water heating demand in the building, the installed solar air to water heat exchanger can deliver a peak solar air to water heating capacity of 64 BTU/sqft/hr.
11. Annually, the system will provide heat to the water at a rate of 51.6 million BTU/year, 13,057 BTU/sqft/yr, 1,088 BTU/sqft/mo. With a larger water heating demand in the building, the installed solar air to water heat exchanger can provide an average solar air to water heating capacity of 213.4 million BTU/ year, 53,947 BTU/sqft/yr, 4,496 BTU/sqft/month.

12. For the months of April to October, the 2 fan system will provide heat to the water at an average rate of 38.9 million BTU/sqft/year, 9,832 BTU/sqft/7 months, 1,405 BTU/sqft/month. With a larger water heating demand in the building, the installed solar air to water heat exchanger can a provide an average solar air to water heating capacity of 162.0 million BTU/sqft/ 7 months, 40,959 BTU/sqft/7 months, 5,851 BTU/sqft/month.
13. With one fan operation, the water heating system will produce 47.6 million BTU/year. With a larger water heating load and one fan operation, the installed solar air to water heat exchanger, can provide an average solar air to water heating capacity of 159.0 million BTU/sqft/yr.
14. With two fan operation, the system will provide an average of 1.8 times as much heat energy as the equivalent electric energy used to power the fans and pump.
15. With one fan operation, the system will provide an average of 2.8 times as much heat energy as the equivalent electric energy used to power the fan and pump. With a larger water heating demand in the building, the system will provide an average of 9.4 times as much heat energy as the equivalent electric energy used to power the fan and pump. During the peak predicted hourly performance, with one fan and a larger water heating demand, the system provides 33.6 times as much heat energy as the equivalent electric energy required to run the fan and pump.

Appendix A-2: Outdoor Air Preheat, Direct Space Heat, and Roof Heat Loss Reduction,

Solar Air Heating Roofs, For Outdoor Air Preheat, Direct Space Heat, and Reduced Roof Heat Loss

Executive Summary:

Background: American Solar, Inc. evaluated its solar air heating roof system on the delivery of solar heated air for space heating, outdoor air preheating, and water preheating. This analysis is part of a larger project to document the overall annual energy and life cycle roofing benefits of a solar air heating roof.

The project is funded by the Department of Defense Environmental Security Technology Certification Program (ESTCP) (Ref. 1). The Solar roofed building is the Gaffney Fitness Center at Fort Meade, MD.

The testing of the solar roof showed that the system can consistently provide solar heat to the outside air intakes and directly to the gym and that it reduces heat loss through the roof. The testing and analysis created a 'first of its kind' analytical performance model of an unglazed solar air heating metal roof.

Experimental Approach: A set of temperature sensors were installed within and around the new solar roof. This included:

- a set installed in the outlet from the solar roof to the outdoor air intakes of the air handler for the gym and
- a set installed at the solar air to water heat exchanger plenum which can supply solar air directly to the gym.

Temperature readings were taken every 15 minutes from late June 2012 thru early January 2013 along with other readings. Local weather stations with time stamped solar insolation, wind speed, and ambient temperature data were used to track environmental conditions.

Findings: The following summarizes the findings with a focus on creating a predictive model of solar temperatures and its application to energy and economic predictions for similar systems:

1. The delivered solar air temperatures can be predicted with good precision for daily, monthly, and annual analysis using only local solar and weather data inputs.
2. The prediction is suitable for use with standard environmental data such as the typical meteorological year (TMY) data to generate weekly, monthly, and annual solar air temperatures for energy delivery.
3. The prediction of delivered solar air temperatures <u>for analysis of any specific hour</u> requires additional solar inputs to improve the accuracy of prediction at start up, shut down, and peak mid-day hours. Addition of hourly solar elevation data and

outdoor temperature and other environmental elements (wind gusts, etc.) can improve the prediction for short term specific hourly modeling use.

4. The prediction of solar air temperature and operating hours can be applied to any similar system using TMY data and utility rates in order to establish the energy savings and economic benefits of installing other solar air heating metal roofs.

Results:

1. The solar air heating roof provided reliable solar heated air for outdoor air preheat during sunny to cloudy days over a 4 month period from October to January.
2. During the cold weather operating hours of the test period, the system supplied solar heated air that averaged 14F above outdoor ambient temperatures and peaked at 43F above outdoor air.
3. Based on modeled projections for annual operations, the system would run for 1620 hours/yr and deliver 162 million BTU/yr of heat to the outdoor air intakes, savings 179 million BTU/yr in natural gas at the boiler.
4. The solar roof keeps the old, covered over, built up roof (BUR) surface 18.6F warmer than the outside air temperature during the winter months from November thru April, averaging 60.7 F, when the exposed BUR would average 42.2F.
5. The winter heat flow reduction from the insulating value of the solar roof equals 21 million BTU/yr, saving 23 million BTU/yr in gas at the boiler.
6. The winter energy delivery for direct space heat to the gym is 41 million BTU/yr with an average temperature of 92.8F operating for 550 hours whenever the solar temperature is above 78F. This saves 45 million BTU/yr in gas at the boiler.
7. Total natural gas energy savings of 248 million BTU/yr can be achieved with the system operating.
8. The system provides 25,827 BTU/sqft/yr in natural gas savings from outdoor air preheat, direct space heat, and reduced heat loss, when using a metric of 1 sqft/1 cfm of solar air flow (7,263 cfm actual flow).
9. During the winter months, the calculated total peak hourly heat flow for outside air preheat and direct space heat is 60 BTU/hr/sqft when using 3,797 sqft to match the typical 1 cfm/sqft design.

Introduction:

There has been very little published data on the performance of solar air heating roofs that use conventional metal roofing as the solar air heating surface. While there has been some published data regarding the temperature in residential attic spaces with minimal air flow, there is very little data on systems that use active, fan driven air flow to collect solar heated air. Jones (2, 3) described the heat loss and solar performance of unglazed metal panels vs. wind speed.

The testing and analysis of the data collected as part of this DOD ESTCP project was designed to confirm the performance of the solar air heating metal roof.

The solar air heating roof retrofit on the Gaffney Fitness Center (Fig. A-2, 1&2) involved the installation of a black metal standing seam roof over a metal substructure with fiberglass and radiant barrier insulation. This retrofit was installed directly over the existing built up roof (BUR) which was on top of a polyisocyanurate (Polyiso) board insulation and corrugated metal deck. Inside the building, at the ceiling of the gym, a 3" thick fiberglass insulation with cloth jacket covered the bottom of the metal deck.

Figure A-2, 1 Gaffney Aerial View

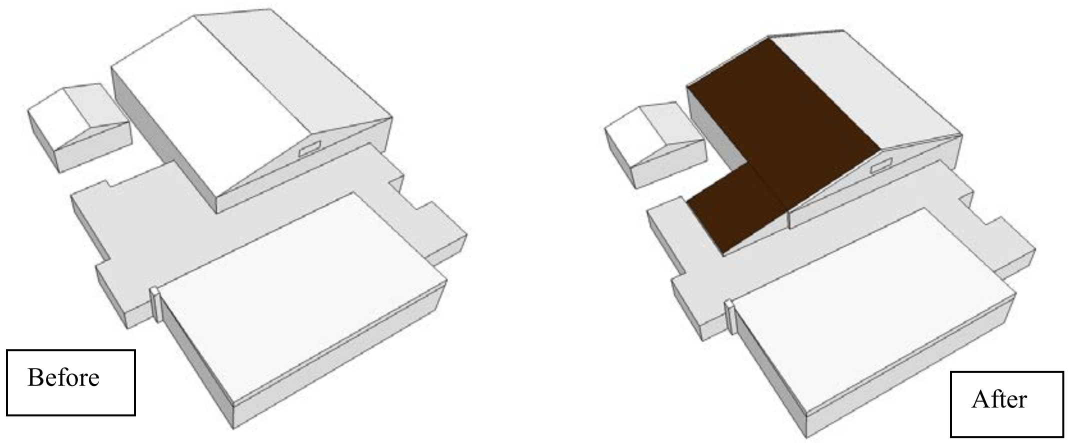


Figure A-2, 2 Before and After

The schematic Figure A-2, 3, shows the system as proposed at the start of the project. Following award of the ESTCP contract, the Corps of Engineers commenced a separately planned and funded HVAC upgrade to the gym which relocated the outside air intake on the southeast exterior wall. The new location of the outside air intake is on an air handler on the ground, to the southwest of the gym. As a result, American Solar adjusted its design to install the solar air plenum within the new solar mechanical room and to run insulated ductwork down to the air handler on the ground

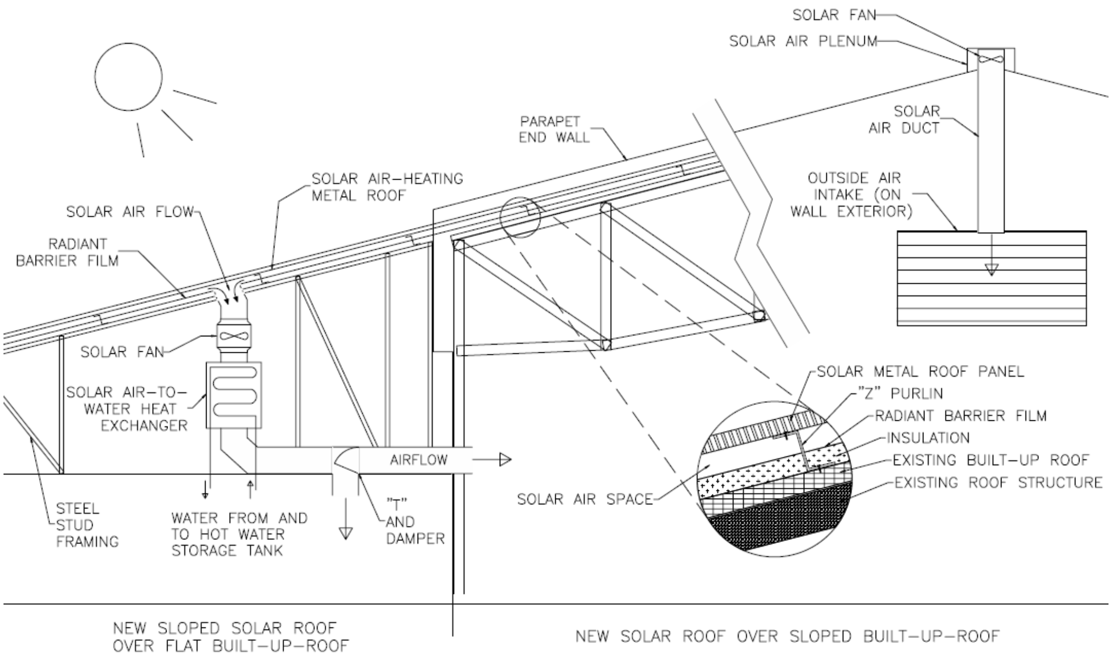


Figure A-2, 3 Concept Schematic Section

The schematic below, Figure A-2, 4 shows the revised arrangement of the Outdoor Air Preheat ducts and fans. Fans 3&4 are now installed adjacent to the old exterior southwest wall of the gym and draw solar heated air down and across the roof to a new plenum that is installed above the old gutter and fascia.

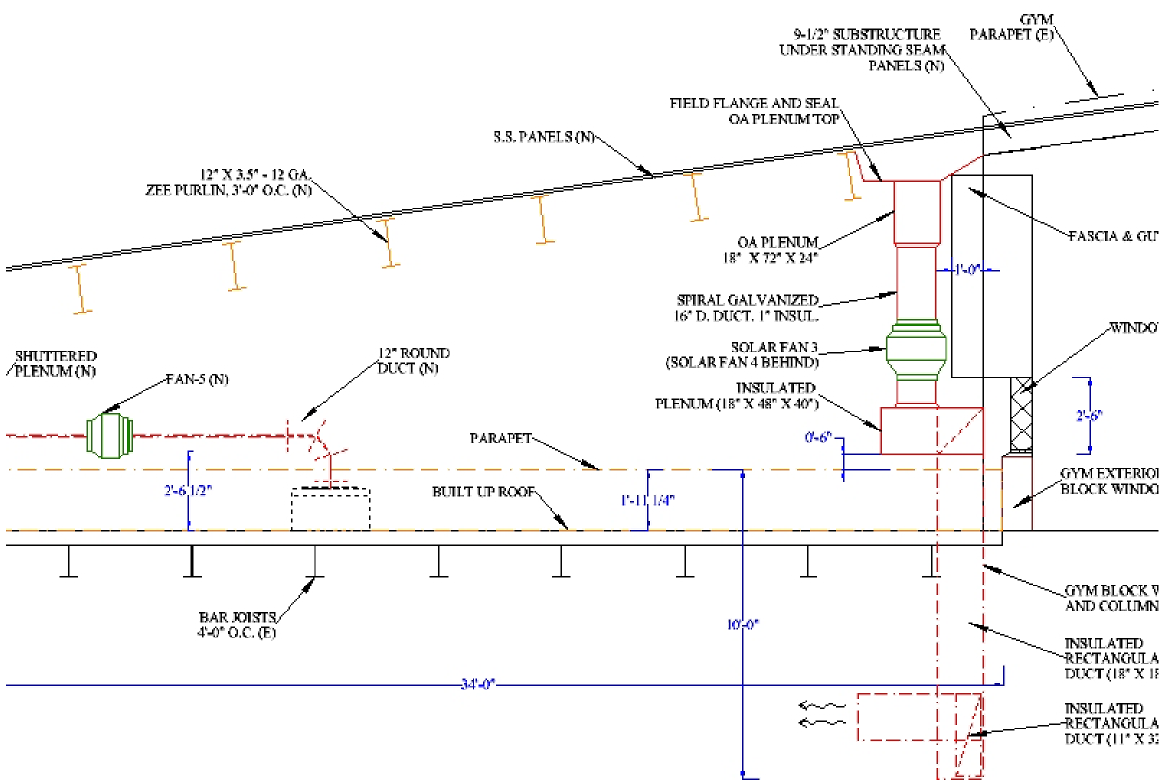


Figure A-2, 4 Revised Schematic Section As-Built

The drawing below, Figure A-2,5 shows the plan view of the solar mechanical room, showing fans 3&4 to the left and fans 1&2 and the air to water heat exchanger to the right. The air discharge from fans 1&2 is normally through the exterior wall to the right when preheating domestic water in the warmer months and through the gym wall on top when providing direct space heat during the heating season.

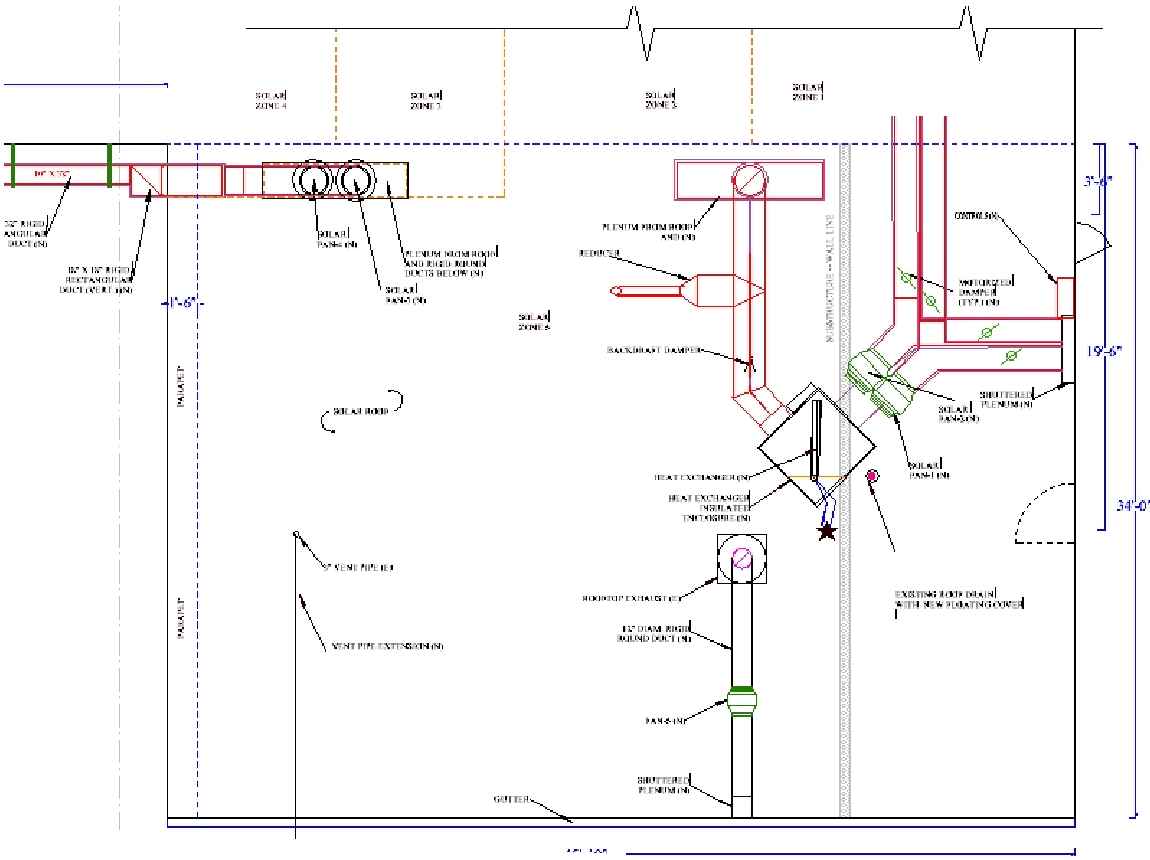


Figure A-2, 5 As Built Duct Plan

Several photos and graphics (Figures A-2, 6-12) show the construction of the system.

Figure A-2, 6 Aerial Photo, As Built

As Installed Aerial Photo of Solar Roof on Gym Roof

Existing Built Up Roof on Gym Before Solar Roof Installation

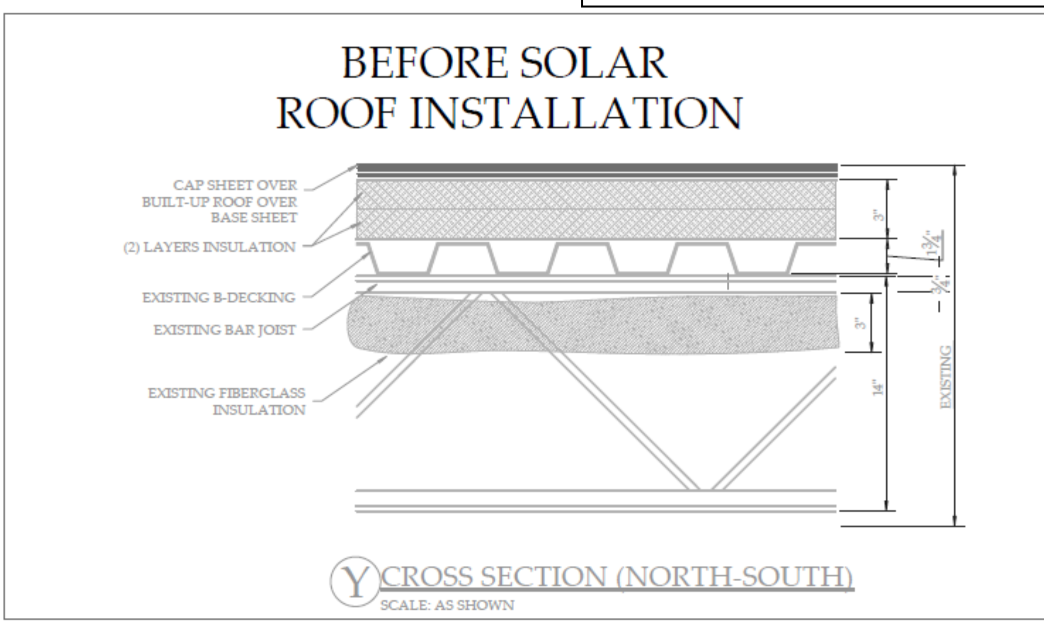
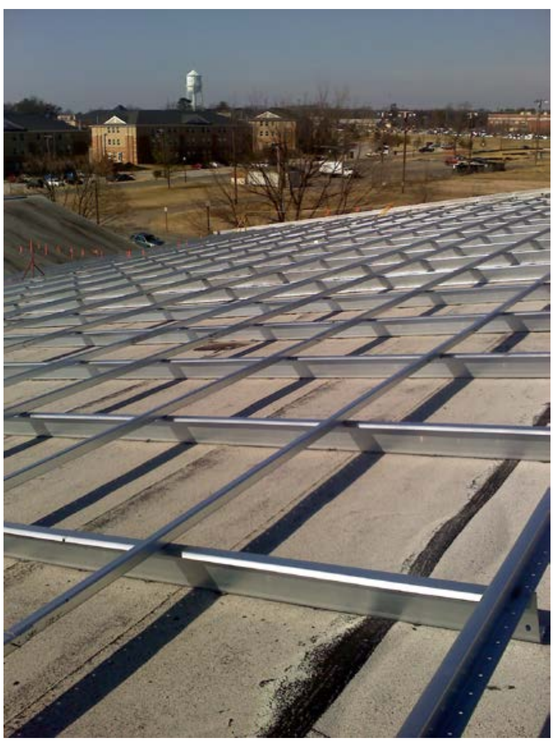


Figure A-2, 7 Roof Section Before Solar

Figure A-2, 9 Old Sloped Built Up Roof on Gym

Figure A-2, 8 Gym Interior Ceiling



Old Sloped Built Up Roof on Gym,
Gym Interior Ceiling,
and
Solar Roof Support Structure on Gym Roof

Figure A-2, 10 Solar Roof Support Structure on Gym Roof

Solar Roof Panels being installed over
Fiberglass and Radiant Barrier Insulation
and
As-Built Solar Roof Section Drawing

Figure A-2, 11 Solar Roof Panel Installation over Insulation

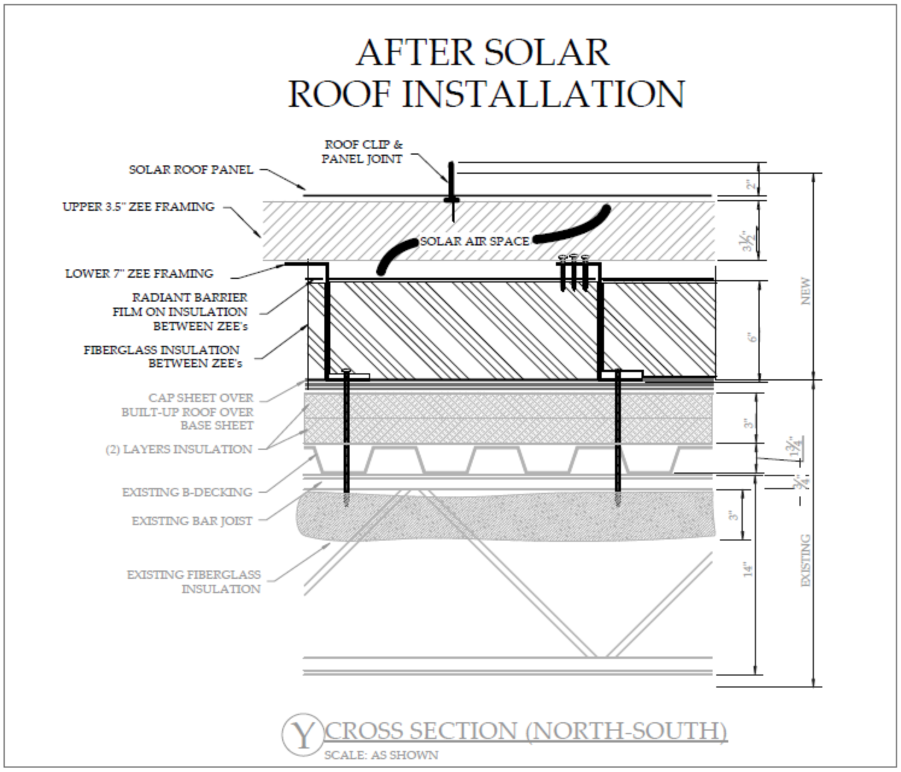


Figure A-2, 12 Roof Section, AS-Built

To document the thermal performance of the solar roof, temperature measurements were made with spot infrared thermometer readings of various surfaces and by data logging of temperatures with numerous, fixed 10k ohm thermistor sensors embedded in the solar roof and arranged at various locations in the solar ductwork. Outside air temperature and wind and solar conditions were taken from a local USDA meteorological station. The temperature and air flow measurements generate overall thermal performance of the roof and solar air heating for outdoor air preheat and direct space heat.

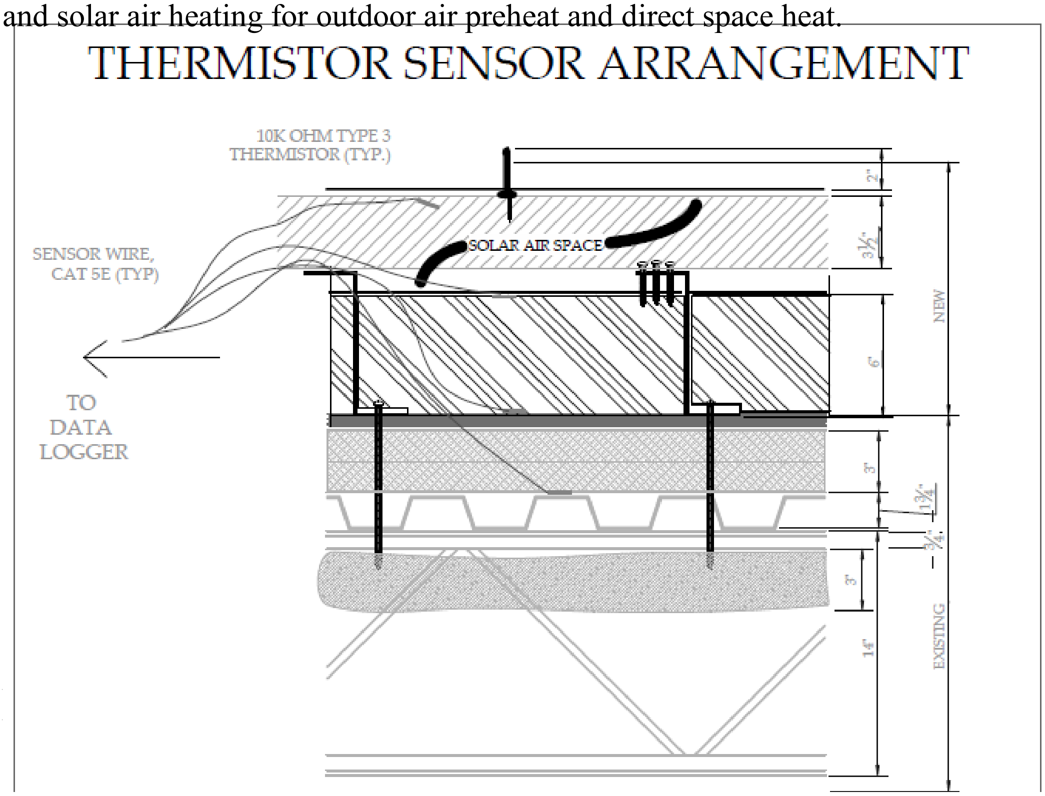


Figure A-2, 13 Thermistor Sensor Arrangement, Roof Section

During construction of the solar roof, several temperature sensors were placed at strategic locations within the roof. The sensor at the top of the solar air space was similar to others placed throughout the roof. This sensor location is about 8' below the ridge in zone 1 and is used control the differential thermostats for the solar fans. See Figures A-2,13-15.

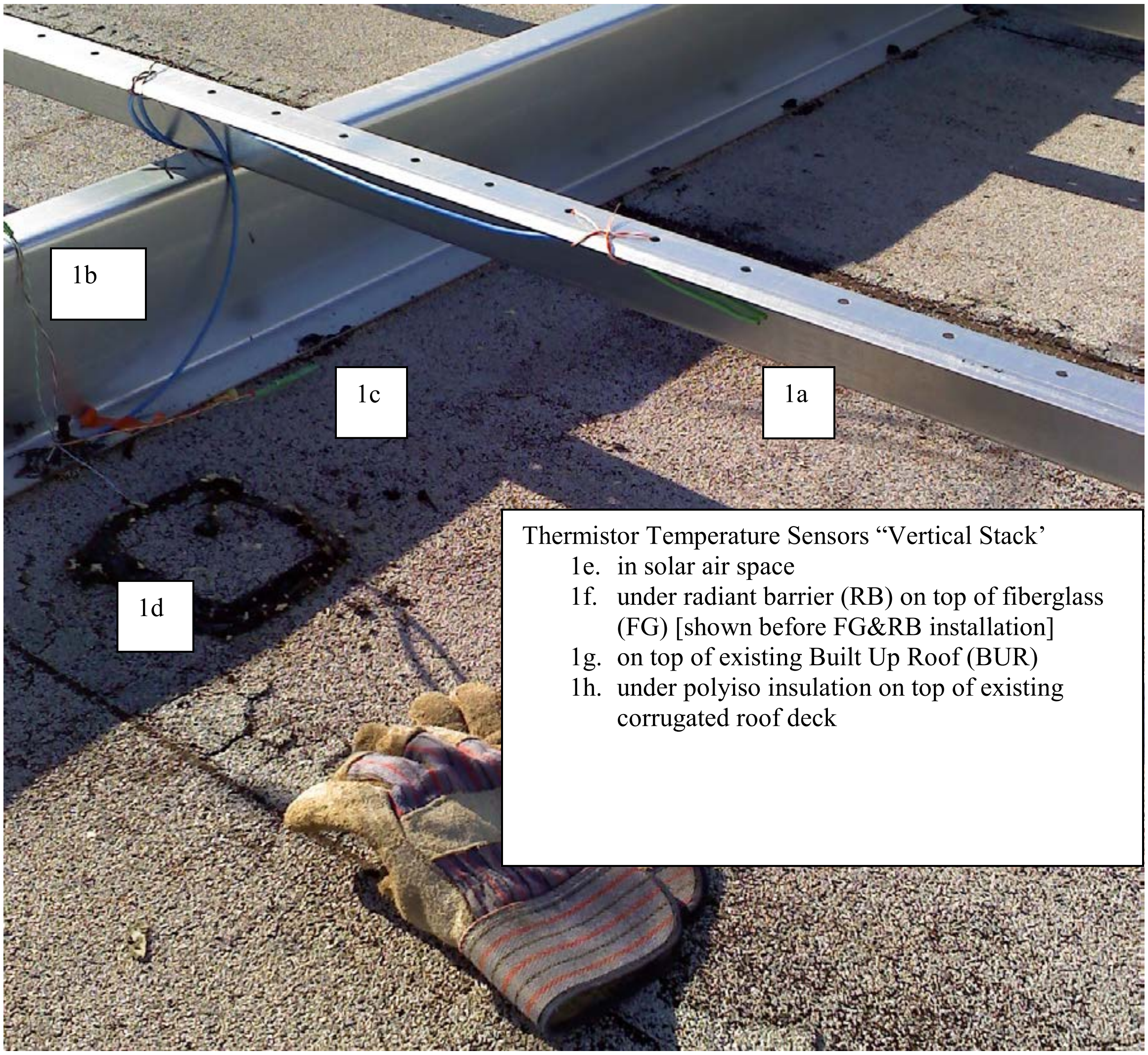


Figure A-2, 14 Thermistor Sensor Arrangement, Vertical Stack

During the testing, beginning in late June, 2012, temperatures across the solar roof were recorded at 15 minute intervals at all these temperature sensors. During the daytime hours, the solar fans were running, drawing outdoor air from the ridge air inlets down through the solar air space to the outlet in the solar attic/mechanical space created below the eaves of the old gym roof.

In addition, on June 28, 2012, shortly before local noon (11:55 EDST, ~10:55 Solar time), a series of surface temperatures were taken using a hand held infrared (IR) thermometer. The surface temperatures were on the existing, exposed built up roof (BUR), the new built up roof flashing that ties in the old BUR to the new solar metal roof at the ridge, and at various locations on the field of the solar metal roof and the ridge. Additional IR measurements were taken inside the gym at the ceiling below the vertical stack of sensors, at the gym floor, and outside on a shaded target in air at 4' above ground level. See Figure A-2, 15 and Table A-2, 1 below.

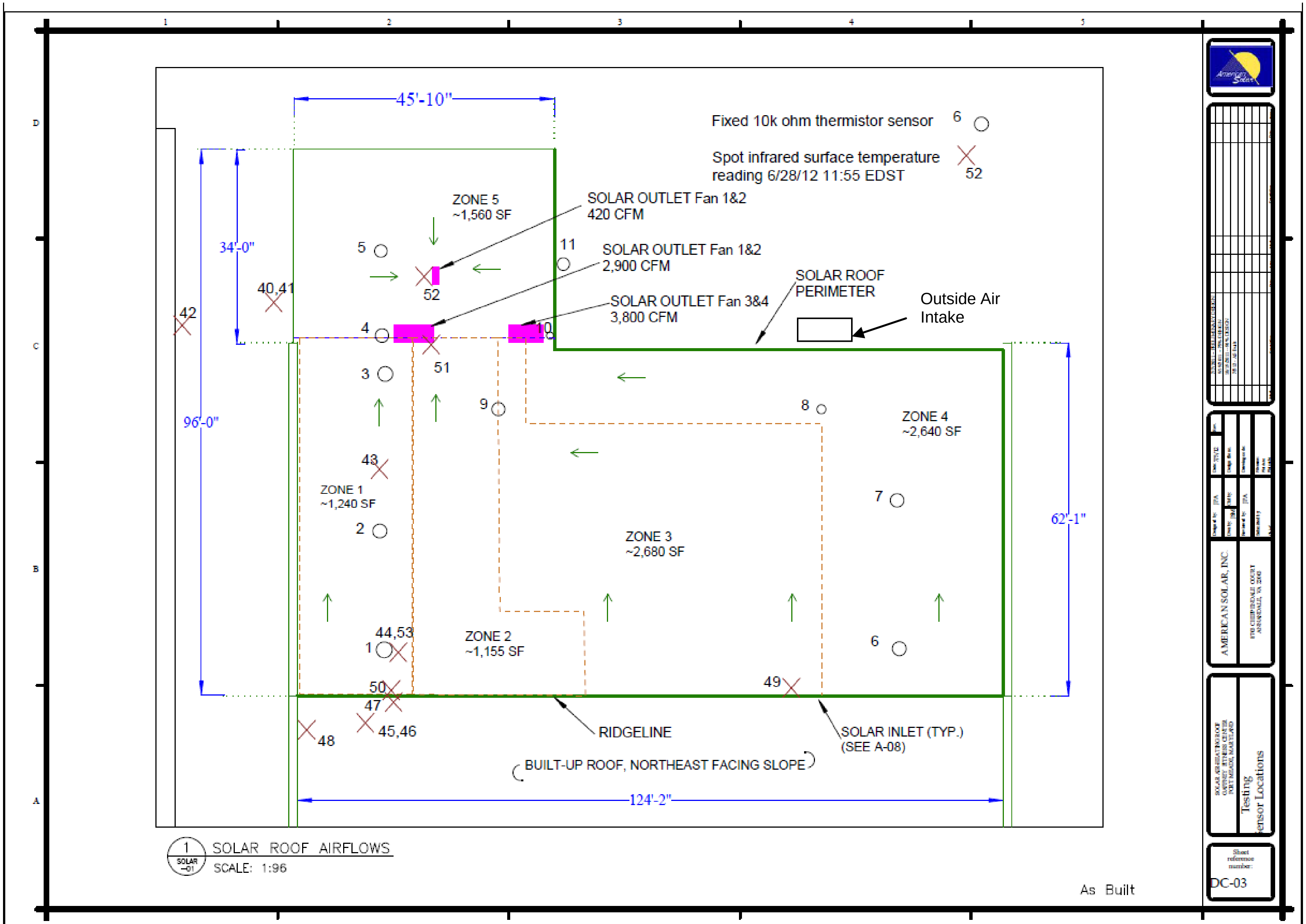


Figure A-2, 15 Thermistor & IR Temperature Reading Locations

Solar Roof Temperature Sensor and Spot Infrared Thermometer Locations		
10k ohm Thermistors, fixed sensors, data logging at 15 minute intervals		
Location	Description	Service
1	Zone 1 High	BUR stack, Solar Air
	1a	Hi, in solar air space
	1b	BUR Belo RB, Below radiant barrier, on top of fiberglass insulation
	1c	BUR Belo FG, Below fiberglass insulation, on top of old BUR
	1d	Belo ISO, Below polyiso insulation, above corrugated metal roof deck
2	Zone 1 mid	Solar Air
3	Zone 1 Low	Solar Air
4	Attic Air	Attic Air 8' above low slope roof BUR
5	Heat Exchanger	Water, Solar air
	5a	Solar air into HX, solar air to air-to-water heat exchanger
	5b	Solar air out of HX, solar air out of air-to-water heat exchanger
	5c	Solar h2o into HX, cold/preheat water to air-to-water heat exchanger
	5d	Solar h2o out of HX, solar preheated water out of air-to-water heat exchanger
6	Zone 4 High	Solar Air
7	Zone 4 Mid	Solar Air
8	Zone 4 Low West	Solar Air
9	Zone 4 Low East	Solar Air
10	Fan 3&4 Outlet	Solar Air
11	Outdoor Air	Outdoor Air
12	Cold City Water	Water into solar preheat loop
13	Return Water to Building	Solar preheated water into building water heating loop
IR thermometer, spot readings, 6/28/12 11:55 EDT		
40,41	Existing flat BUR in sun	BUR
	40	BUR with ~25-40% granules missing
	41	BUR with ~0-5% granules missing
42	Existing BUR Flashing in shade	BUR
43	Solar center of Zone 1	Solar Roof
44	Solar Zone 1 Hi above BUR	Solar Roof, above the vertical stack sensors 1a-1d
45,46	Existing North BUR in sun	BUR
	45	BUR with ~20-30% granules missing
	46	BUR with ~10-20% granules missing
47	New BUR Flashing in sun	BUR
48	Existing BUR Flashing in shade	BUR
49	Zone 3 Solar Ridge	Solar Roof
50	Zone 1 Solar Ridge	Solar Roof
51	Zone 1 Plenum	Solar Roof
52	Zone 5 Plenum	Solar Roof
IR thermometer, spot readings, 6/28/12 12:50 EDT		
53	Gym interior ceiling below BUR Stack	Gym Ceiling
54	Gym Floor below BUR stack	Gym Floor
55	Outdoor air in shade	Outdoor shade

Table A-2, 1 Solar Roof Sensor and IR Locations

Solar Fans 1& 2 draw solar air from roof zones 1, 2, and 5. During most of the warmer months, the fans discharge solar heated air across an air to water heat exchanger to preheat domestic cold water before it goes to the domestic hot water boiler. However, during the space heating season, when the solar heated air in the roof is sufficiently hot (>78F), and the building automation system calls for heat, the solar air can be discharged to the gym to provide heat. This is called direct space heating.

Fans 3&4 draw solar heated air from roof zones 3&4. They discharge solar heated air to the outside air intakes of the air handler located on the ground near the gym wall. When the solar heated air is warmer than the outside air by a set differential temperature, solar fans 3&4 turn ON and stay ON until the solar air temperature drops below a set differential.

The following chart, Figure A-2,16 shows the temperatures and fan ON-OFF hours for one day. Note that during this day, like most of the testing period, the solar fans turned ON and OFF when the solar roof air temperature was about 19F warmer than the outside air. This will be discussed later with regards to maximizing the solar output by adjusting the ON-OFF temperatures.

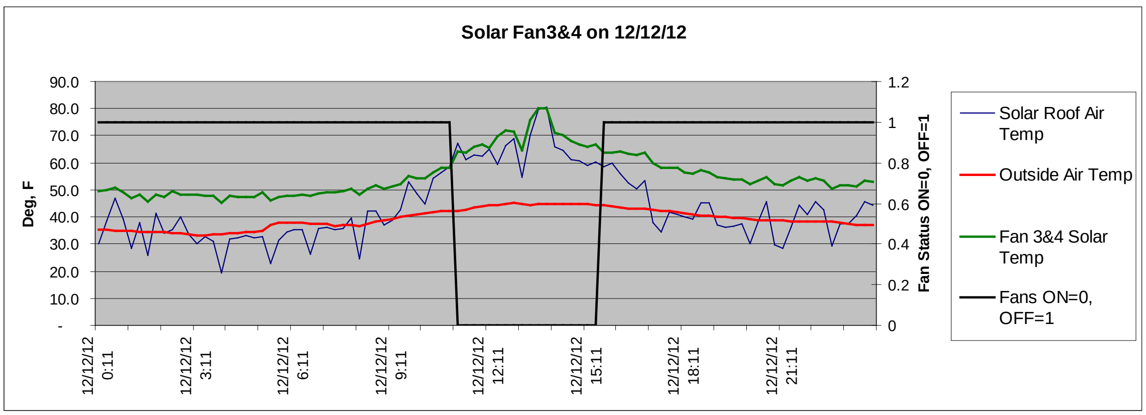


Figure A-2, 16 Solar Air, Gym BUR, & OA Temps

During this one day period, the fan ran from 11:15 to 15:30, 4 hours and 15 minutes. The average temperature difference between outside air and Fan 3&4 Solar Air was 24.9F.

During a commissioning period in May, the solar air flow from fan 3&4 was measured at 3,797 cubic feet per minute. Considering an average solar temperature of 65F during the ON hours, and the specific volume of air at 13.3 cubic feet per pound of dry air, the total mass flow of solar heated air is calculated. Using a specific heat of air of 0.24 BTU/#/DegF, we can calculate the heat in the solar air relative to the heat in the outdoor air going to the outdoor air intake of the air handler. The heat added to the outside air intakes during that 4.25 hour period was 461,000 BTU for that day.

The same approach works for fans 1&2 providing direct space heat to the gym with one distinction. Unlike the case with fans 3&4, which can operate at any delivered temperature that is warmer than the outside air temperature, in the case of fans 1&2, the use of those fans is limited to only those hours when the solar air temperature is above 78F. This approach ensures that fans 1&2 only provide direct space heat when they are at least 8F warmer than the normal temperature in the gym.

One other phenomenon is evident from the chart above, in Figure A-2, 16. Note that the solar air temperature in the roof is consistently warmer than the outdoor air temperature from about 9:00 to 17:00. The temperature difference is between about 10 and 35 deg. F. Had the solar roof not been installed above the old built up roof (BUR), the old BUR would have experienced temperatures closer to outdoor air temperatures. This would have increased heat loss up through the roof from the warmer gym ceiling below.

The chart below, Figure A-2,17, clarifies this further by showing the temperature of the old BUR that is covered over by the solar roof. The old BUR surface, which is under the fiberglass layer of the solar roof, stays close to about 60F throughout the day, while the outdoor air temperature varies from the low 30s to the mid 40s. This 15 to 25 deg F temperature difference cuts the heat loss from the warm air at the ceiling of the gym to the BUR layer. In fact, during the hours from 9:00 to 17:00 the warmer solar air above the fiberglass in the roof is helping to drive heat down to the BUR below the fiberglass, raising the BUR temperature from 57F in the morning to 62F in the evening. This shows that the solar roof not only prevents heat loss through the roof but actually helps reverse the heat loss that would occur if the BUR were at outdoor air temperatures.

This substantial reduction in the temperature difference between the ceiling and the warmer BUR under the solar roof vs. the cold, exposed BUR represents a significant reduction in the roof heating load on the building.

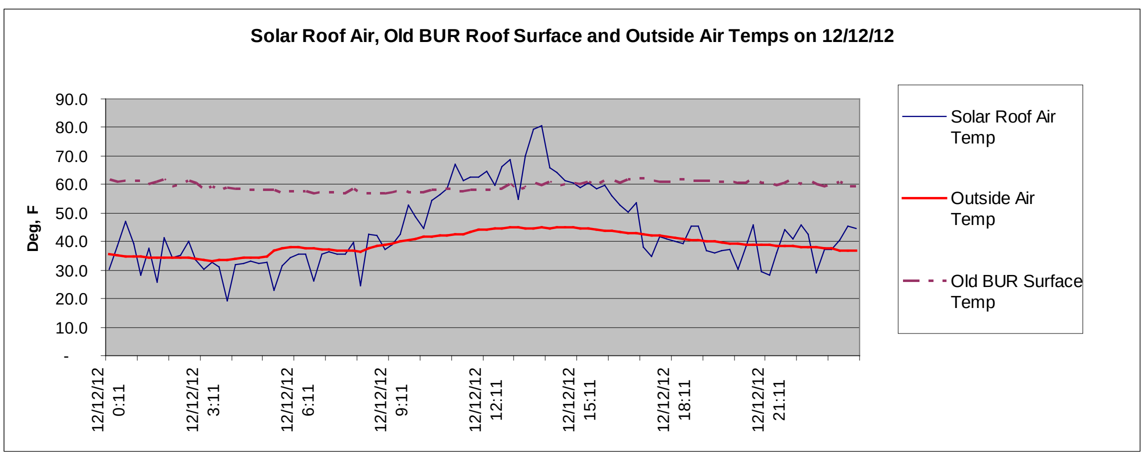


Figure A-2, 17 Fan 3&4 Solar Air and OA Temp

We calculate this heating loss using the methodology in the ASHRAE Fundamentals, 2001 (Ref. 4), which combines the thermal resistance, 'R' values of the components between the top of the BUR and the bottom of the ceiling surface. The individual components have R values as shown in Table A-2,2. The total R value of the assembly from the top of the BUR to the inside of the ceiling insulation is 36.

Component	R value
BUR	.33
Polyiso Insulation	24
Air Space in corrugated deck	.91
Fiberglass ceiling insulation	11

Table A-2, 2 Solar Roof R-Values

Over the course of this one day, with a 20F average temperature difference between the covered BUR and the Outdoor Air temperature, the heat loss can be calculated using the R value of the roof. The heat loss in BTU/hr/sqft is equal to 20/36 = .56 BTU/HR/sqft. With 9,275 total sqft of solar roof over the old BUR, the heat loss avoided by the insulating value of the solar roof is 5,153 BTU/hr, 123,667 BTU/day.

So, the total heating delivered by the solar roof is the sum of the heat transferred to the outdoor air, the heat transferred by direct space heat, and the avoided heat loss from the insulating roof. In addition, the Gaffney gym is heated by a natural gas fired condensing boiler. The manufacturer's literature indicates that the boiler operates at 90% efficiency at the operating temperatures of the hot water loop. In order to deliver one unit of heat to the gym, the boiler must extract 1.11 units of heat (1/90%) from the natural gas. So, a final energy savings comes from eliminating the inefficiency of burning the natural gas to provide heat. Ultimately, the cost savings in avoided natural gas purchases are important to the economics of the system.

While the solar heating system is very efficient, it still requires energy to gather and distribute the solar heated air. The 4 fans each draw 1,369 watts of power when operating. The cost of the electric power must be considered when evaluating the operation and economics of the solar roofing system. For example, if the solar air is only slightly warmer than the outside air, the dollar savings in natural gas may be less than the electric cost to run the fans.

The system, as installed, had an adjustable thermostatic setting that was set to turn ON when the solar roof air temperature was ~16F warmer than the outdoor air temperature. This was consistently verified by actual turn ON readings averaging 14F greater than outdoor air, well within the range of the adjustable thermostats accuracy. The turn OFF setting for the differential thermostat is 4F above outdoor air temperature and is not adjustable within the differential controller. This permits the solar fans to run when the solar air temperature is just slightly above (4F) the outdoor air temperature.

Permitting the solar fans to run until the DT is less than 4F, can provide useful data on full range of solar roof heating capacity, but it does not always result in the most economical use of the system. For example, using recent electric rates at Fort Meade, the breakeven temperature difference between solar air and outdoor air or gym air is roughly 8.1 degrees F. That is, when the solar air is warmer than 8.1F above outdoor air, there will be positive net cost savings ($gas-$electricity). When the solar air is less than 8.1F above outdoor air for gym air, there will be a net loss for every hour of operations, as the electric costs are higher than the gas savings.

This value varies for each installation based on local electric and gas rates, electric fan power required, and boiler efficiency.

Calculating Solar Energy Performance

Projecting solar air temperatures

The raw data collected from the thermistors in the roof and ducts and the local weather and solar data permit solar air temperatures to be predicted with reasonable accuracy over the course of a day, week, month, and year. To make these predictions, the following independent variables are used in a regression analysis: Outdoor air temperature, Wind Speed, Solar Insolation, and Solar elevation.

The first regression is to determine the solar air temperature in the roof, near the ridge, where the thermistor sensor is located that feeds the signal to the differential controller for fans 3&4. From that regression, the formula is:

Roof Solar Air Temp = -5.82363 + 1.15796 * Outdoor air temp (Deg F) + 0.333505 * Wind Speed (MPH) + 0.045709 * Solar Insolation (W/m^2) + 0.081632 * Solar elevation (Deg)

A sample chart, Figure A-2, 18, is shown below showing the predicted and measured solar air temperatures for a 4 day period. Of these days, the solar fans ran when the roof air was above the outside air temperature.

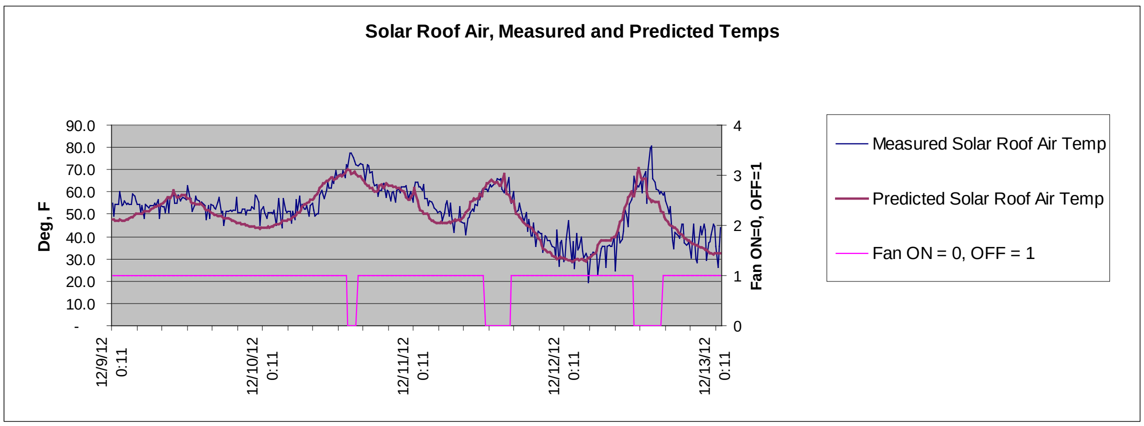


Figure A-2, 18 Solar Air, Measured and Predicted

The chart below, Figure A-2,19, shows that this simple model typically slightly under predicts the temperature during peak solar hours and over predicts the solar temperatures during low temperature, pre-dawn hours. A series of adjustments were made to account for these variations in the predicted temperature. These include adjusting peak mid-day solar temperatures up by 12% when predicted solar temperatures were above 80F, adjusting low predicted solar temperatures down by 3% below 50F and down by 12% below 30F. Figure A-2,19, shows the actual, predicted and corrected prediction for several days in November and December.

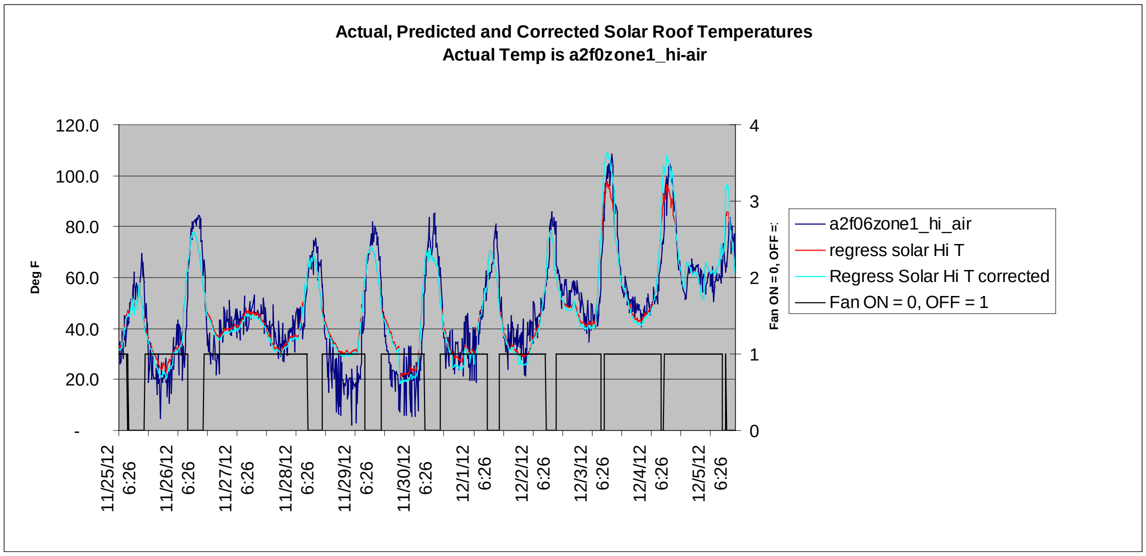


Figure A-2, 19 Corrected Solar Air Temps

Once the solar roof air temperature was predicted, a second analysis was made to determine the Turn ON and Turn OFF temperatures for fans 3&4. This includes both the OFF hours when there is no 'call for heat' from the building automation system and when the solar differential thermostat senses that the solar roof temperature is too cold to provide heat to the outdoor air.

A review of the actual ON-OFF data indicated that a new call for heat occurred whenever the outdoor air temperature was below 55.8F. Once the solar fans turned ON, the systems would stay on until the outdoor air temperature rose above 63F and the call for heat was cancelled. Using these ON-OFF temperatures and calls for heat, the solar differential thermostat response could be determined.

This determination looked at the temperature difference between the actual solar roof temperature and the outside air temperature. The average of all the actual temperature differences when the system turns ON was used to predict when the system would start running. A similar analysis was used to determine the Turn OFF temperatures. A modifier was added to these to eliminate any hours when the solar angle was below 20 degrees above the horizon, which was an angle below which the fans never ran in the early morning or late afternoon.

Once the solar roof temperatures and ON OFF times were predictable, a second regression analysis was performed to predict the delivered solar air temperature from fans 3&4. Due to the location of the outlet plenum for fan 3&4, about 40 feet from the controlling sensor near the ridge, the delivered solar air temperature for fan 3&4 is slightly lower than the solar roof sensor temperature. The second regression analysis of the delivered solar air temperatures adjusts for this difference, based on actual delivered solar temperatures at fan 3&4.

The second regression of delivered solar air temperature used the same independent variables of: Outdoor air temperature, Wind Speed, Solar Insolation, and Solar elevation.
The formula is:

Fan 3&4 Delivered Solar Air Temp = 35.70589 + 0.82378 * Outdoor air temp (Deg F) + -0.41746 * Wind Speed (MPH) + 0.026139 * Solar Insolation (W/m^2) + -0.26654 * Solar elevation (Deg)

Figure A-2,20 shows the predicted fan 3&4 temperatures <u>during only the ON hours</u> over the same 11 day period shown above. While any particular hour may be off the averaging of the regression analysis ensures that the average temperature difference over time is an accurate representation of the actual average.

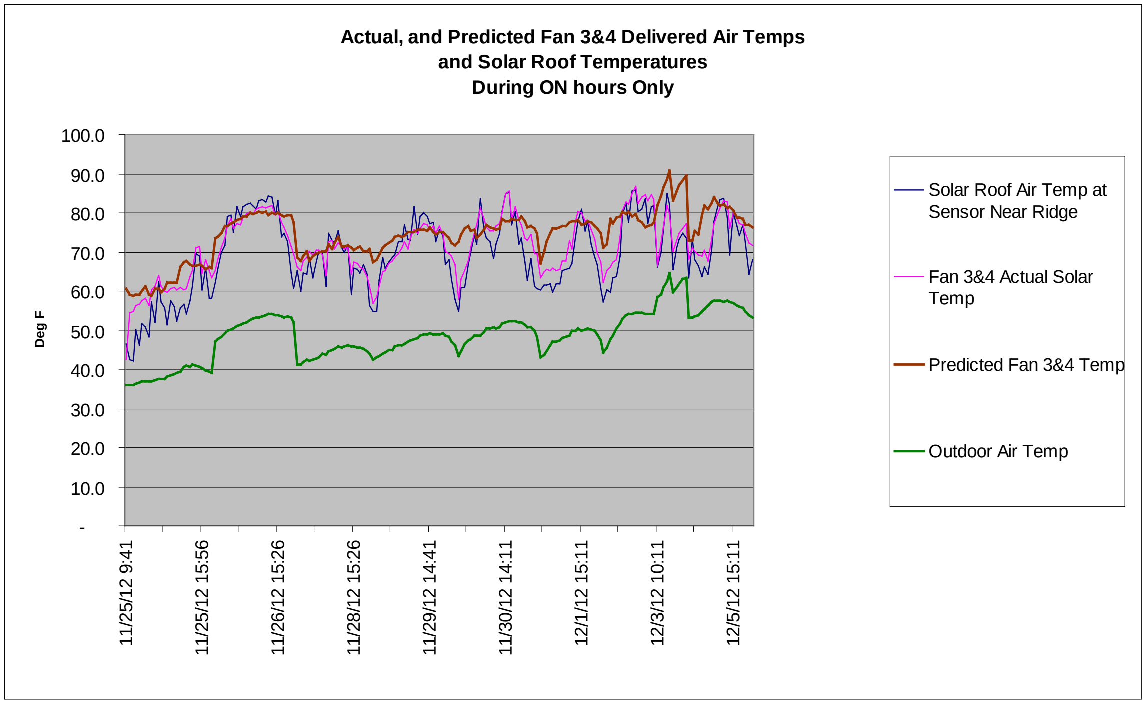


Figure A-2, 20 Actual & Predicted Fan 3&4 ON Hour Temps

<u>Predicting Heat Transfer to Outside Air</u>

With prediction of the ON OFF times and delivered solar air temperatures from fan 3&4, the prediction of the heat transfer into the outside air intakes is possible. This prediction uses the temperature difference of the solar air from fan 3&4 and the outdoor air and the air mass flow to calculate the heat delivered to the outdoor air intakes.

For any given period, the increased heat transfer from solar air vs. outdoor air is equal to the mass flow of air times the delta T (Solar – Outdoor air) times the specific heat of air.
For example, at 14:11 on 11/26, the Outdoor air temperatures was 53.7F and the solar air temperature was 81.7F , with a delta T of 28F. The volume flow was 3,797 cubic feet per minute which yields 17,129 pounds of air per hour. So, the heat transfer to the outdoor air intakes is 17,129*28*.24 = 115,169 BTU/HR.

The fan energy to run the 2 fans electrical energy demand is 2,738 watts, which is equivalent to 9,345 BTU/HR. This yields a coefficient of performance (COP, energy delivered/energy consumed) of 12.3 during this 1 hour.

With recent electric rates at Fort Meade, of $0.118/kwhr, the cost to run the fan is $0.32/hour. With natural gas rates at $8.87 per million BTU and a 90% efficient boiler, the cost of gas heat is $9.70 per million BTU delivered to the gym. So the gas savings would be $1.12 per hour. The net savings would be $0.80 for this one hour of operation.

[Note: The breakeven solar temperature differential with these energy rates is 8.1F above the outside air temperature. This equates to 33,308 BTU/hr for solar heated outside air delivered. When operating at any temperature at or above this temperature differential, the systems will produce positive cost savings every hour of operation. This is also the temperature differential that maximizes the number of operating hours and cost savings.]

Annual energy projection for Outside Air Preheat

The annual energy projection for outdoor air preheat uses the Typical Meteorological Year 3 data for Baltimore and the solar elevation data from NOAA to predict the hourly weather and solar data and apply the regression analyses.

The data indicates that the outdoor air preheat, as installed at Gaffney, will operate for 749 hours per year and deliver 107 million BTU of heat to the outdoor air intakes. This value is calculated using the ON differential temperature of between 15 and 13F (Solar roof air – Outside air) when turn ON and OFF occur, respectively. This matches the actual ON-OFF temperatures as installed.

However, when set to operate at the differential temperature of 8.1F, the system will deliver solar heat to the outdoor air intakes for 1,620 hours and will deliver 162 million BTU of heat, saving 179 million BTU of gas heat that would have been required to compensate for cold outside air. The cost savings would be $1,571 in gas and a net savings of $1,047 in gas and electricity ($-523).

Annual energy projection for Direct Space Heat

The Gaffney system is set up to deliver solar heated air directly to the gym whenever the solar air is 78F or warmer and there is a call for heat. The solar air is delivered from fans 1&2 through the heat exchanger, without the domestic water circulating pump running, and into the gym. The solar air delivered simply overpressurizes the gym and forces out existing conditioned air from the gym, replacing it with warmer solar heated air.

The 78F temperature is selected to ensure that solar air is 8F above the typical 70F gym air during the heating season. If the solar air were below 70F, the existing conditioned air in the gym would be pushed out by the supply of cooler solar air and no heating would take place. If the solar air were between 70 and 78, the heat added would not save enough money in natural gas to overcome the cost of running the fans.

Using the same regression analysis for solar roof temperature we can predict the hours when the solar air temperature is above 78F. With an annual simulation using TMY3 solar and weather data, the direct space heat would run for 550 hours and average 92.8F supply temperature. This equates to 41 million BTU delivered to the gym air and 45 million BTU in natural gas savings.

Predicting energy savings from Increased Insulating Value

The solar roof system increases the insulating value of the roof by adding a layer of 6” thick fiberglass insulation and a 3” deep air space that is warmer than the outside air for many hours of the day. For the Gaffney system, the fiberglass insulation sits directly on the old built up roof (BUR). A thermistor sensor is installed under the fiberglass and on top of the old BUR and records the temperature of the old BUR every 15 minutes.

Without the solar roof installed, the BUR would be exposed to outside air and would maintain a temperature close to the outside air temperature. While there would be some minor temperature rise from solar heating of an exposed BUR during the winter months, it is minor compared to the effects of the outside air, clouds, wind, rain, and nighttime hours when the exposed BUR would be close to the outside air temperature.

Using the difference between the outside air temperature as a proxy for an exposed BUR (without solar roof), and the temperature of the BUR under the fiberglass of the solar roof, gives a value that can be used to calculate the heat flow through the roof. To do this we use the R value of 36 described earlier and the delta T from the OAT and BUR under the fiberglass. The heat flow per square foot per hour is equal to DT/R.

Using the annual simulation, the solar roof saves 20.8 million BTU of heat flow through the roof of the 6 month heating season from November through April, which cuts natural gas use by 23.1 million BTU. Gas cost savings would be $202 per year.

Combined energy savings

The three energy savings elements are the outside air preheat, the direct space heat, and the reduced heat flow from added insulation.

Table A-2,3 below summarizes the savings using 2 methods. First, the savings are calculated ‘as installed’ with turn ON-OFF differentials of about 18F. Second, the savings are calculated using a turn ON-OFF differential of 8.1F to maximize cost savings.

	AS INSTALLED		MAXIMUM SAVINGS	
Annual Savings or Operating Hours	Million BTU/yr or hours/yr	$/yr	Million BTU/yr or hours/yr	$/yr
Hours ON OA Preheat	749		1,620	
Gas Energy Savings OA Preheat	119	1,039	179	1,571
Electric Energy Use OA Preheat	(2,051 kwhr)	(242)	(2,738 kwhr)	(523)
Net		**798**		**1,047**
Hours ON Direct Space Heat	550		550	
Gas Energy Savings Direct Space Heat	45.4	396	45.4	396
Electric Energy Use Direct Space Heat	(1,506 kwhr)	(178)	(1506 kwhr)	(178)
Net		**219**		**219**
Hours of Winter Insulating	4380		4380	
Gas Energy Savings Insulating Value	23.1	**202**	23.1	**202**
Total $ savings/yr		**1,218**		**1,467**

Table A-2, 3 Installed & Max Energy Savings

Energy delivery per square foot of roof

The solar roof installed at the Gaffney Fitness Facility has the capacity to deliver much more heat than was delivered during this testing period, because the solar roof area has been designed, for roofing purposes, to cover the entire southwest slope of the roof, not just to meet the selected, limited heating loads. As a result, the values of BTU saved per square foot of installed solar roof are lower than what could be achieved if the building could take full advantage of all the heat available.

The following section discusses the energy delivery per square foot of roof used and describes the maximum heating capacity of the solar roof under conditions where all solar energy is used.

The roof plan shown above describes the various zones of the roof and the square feet per zone. The total area of new solar roof is 9,275 square feet. The roof was divided into 5 zones to comply with fire protection requirements for the re-roof and to divide the solar air flow to support each of multiple fans. The sizing of the zones also balances the draft loss through the roof to each solar fan. As a result, zones 3&4 are larger zones because the air flow path from the ridge to the outlet plenum is longer and more indirect. The larger areas of these zones slows down the speed of the air flow within the roof, reducing resistance to the flow as compared to zones 1&2 which are smaller and have more direct air flow paths.

Combined total air flow for fan 3&4 is 3,797 cubic feet per minute which is within 3% of the 3,915 minimum outside air intake requirements of the air handler for the gym. However, fan 3&4

draw from a total area of 5,320 square feet. This is 0.65 cfm/sqft, which is lower than a nominal value used for most of American Solar's roof designs, of 1.0 cfm/sqft. Had the nominal value been used, the air flow would have been 5,320 cfm, which is 40% more air but also more than the air handler could consistently use for outside air preheat.

So, the solar roof has the capacity to provide at least 40% more air flow, and solar heat, to the outdoor air intakes or other loads, if operated at the 1cfm/sqft flow rate.

For the Direct Space Heat system which operates via fans 1&2, the combined total solar roof area of zones 1, 2, & 5 is 3,955 square feet. The air flow from fans 1&2 into the gym is 3,466 cfm, for a value of .88 cfm/sqft. If the system were operated at 1cfm/sqft, it would deliver 14% more energy than with the current arrangement. However, fans 1&2 are designed primarily to provide air flow to support year round domestic water heating. Greater air flow is not required given the loads served, but could be accommodated if additional loads were served, such as pool heating of other outdoor air preheat loads.

With the full 9,275 square feet of solar roof, and with a larger, more continuous load, such as the pool heating load, the system would likely provide a combined total energy delivery/savings of about 45,000 BTU/sqft/yr, or 420 million BTU/yr. This would save, 465 million BTU of natural gas and $4,075 per year in gas costs. Electric costs would be $590 per year for a net savings of $3,485 per year.

Table A-2,4 provides a breakdown of energy savings from the 3 space heating components; outdoor air preheat, direct space heat, and reduced roof heat loss.

	Demonstration plan goal	Actual Outdoor Air Preheat	Maximum Possible Outdoor Air Preheat	Actual Direct Space Heat	Actual Heat Loss Savings	Actual Total Energy to Air	Maximum Possible Energy to Air
Roof area	Sqft>	5320	5320	3955	9275	9275	9275
Solar Energy to Air	Peak 50 BTU/sqft/hr	48	68	34	0.9	47	60
	Peak 300 BTU/sqft/day	343	399	212	20	318	350
	Peak 4,500 BTU/sqft/mo	4788	6225	2069	474	3903	4727

Table A-2, 4 Energy Savings OA, Direct, & Heat Loss

Note: Values are not additive due to the occurrence at different times and use of different roof areas and air flows.

<u>Annual Natural Gas Savings</u>

From a review of the utility bills, the Gaffney Fitness Facility currently uses 2,399 million BTU per year in natural gas to deliver 2,159 million BTU to the gym for space heat, pool heat, and domestic water heat.

In July, August, and September the average gas purchase from the utility is 7.7 million BTU/month. This would represent just the domestic hot water load, since there is no space heating or pool heating load during these months. We can assume this is representative of the year round domestic hot water heating load, or 93 million BTU/yr of natural gas for domestic hot water heating, delivering 83 million BTU/yr to the hot water via the 90% efficient boiler. The remainder, 2,306 million BTU of natural gas was used for space heating for the gym and pool heating, delivering 2,075 million BTU of heat to the gym and pool.

The Outdoor Air Preheat System delivers 107 million BTU/year as installed, but is capable of delivering 179 million BTU/year when set to at TURN ON-OFF temperature of 8.1F.

The Direct Space Heat System delivers 41 million BTU/year.

The Reduced Roof Heat Loss from added insulation and heating air above the old roof delivers 21 million BTU/year in savings.

So, total energy delivered to the building heating system including heat loss savings from all components equals 169 million BTU per year.
With a 90% efficient boiler as the primary heating system, this equals 188 million BTU of natural gas not purchased.
If the maximum output of the system is delivered, using the 8.1F ON-OFF set point, the total energy delivered would be 224 million BTU/year, saving 248 million BTU/year of natural gas.

This represents 8% of the space heating gas used and 11% if the system is operated at the 8.1F ON-OFF differential. Water preheat savings are analyzed separately but would add to the total savings from the solar roof.

Total Roof Savings

The solar roof is designed to do much more than provide outdoor air preheat, direct space heat, and reduced heat loss. In fact, its three primary purposes are to 1) provide low life cycle cost, high performance weathertight roofing and 2) deliver heat to the building for space heating and water heating and 3) increase the insulating value of the roof to resist winter heat loss.

From a separate analysis, of the various energy and cost savings, the total savings is about $5,500 of which heating savings is over $1,800, or about 30%. Figure A-2, 21 shows the contribution of the solar re-roof to cost savings from each expense.

Additional energy savings opportunities

The one large additional heating load in the building is the pool heating system and that load could be served by an extension of the existing solar air heating system. In addition, there are other outdoor air preheat loads from other air handlers and additional direct space heat could be provided.

Additional solar heat energy could also be delivered by adapting the existing minimum outdoor air volume flows to accept greater solar heated air flow during the heating season. Similarly, adjusting the outdoor air flow when direct solar heating is available, could increase the solar heated fresh air provided to the gym without increasing the exhaust of conditioned air. Both of these approaches would require an adjustment to the sequence of operations programmed into the existing building operations system.

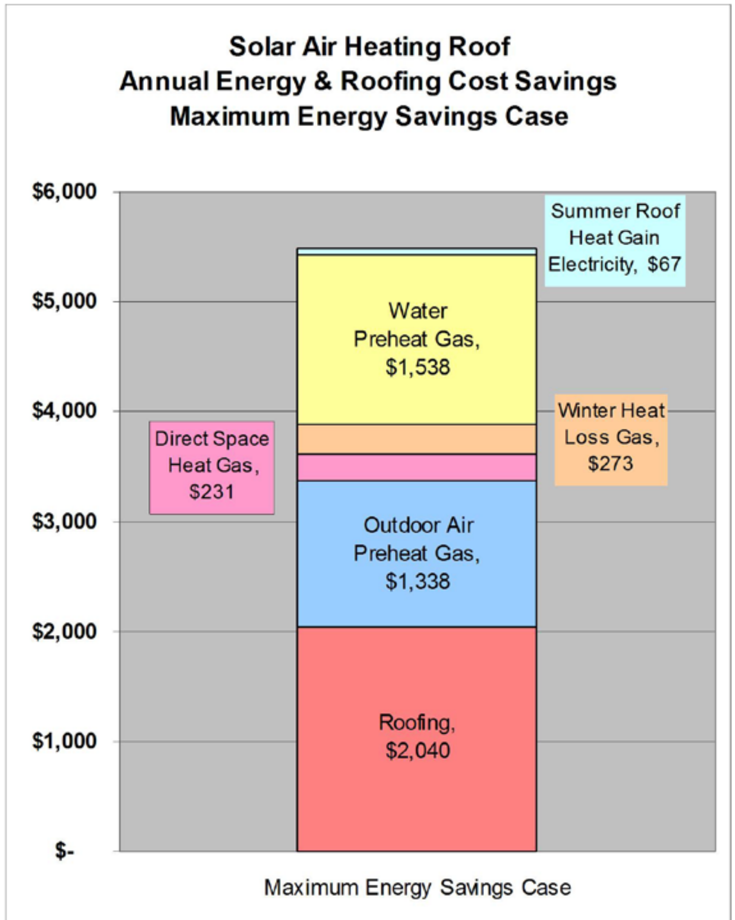


Figure A-2, 21 Solar Roof Annual Energy & Roof Cost Savings

<u>Summary</u>

The solar roof retrofit on the Gaffney Fitness facility has demonstrated and documented the capacity of the systems to deliver heat for outdoor air preheat and direct space heat and to reduce the heat loss by adding insulation and a warm layer of air above the existing roof.

The system is actually capable of providing more heat to the building than is currently being provided, because the roof is larger than needed just to provide energy to the heating and hot water loads. However, because it was designed primarily as a re-roof of a large worn out roof area, the sizing of the roof was primarily determined by the roofing need, not the heating energy needs.

References

1. Department of Defense Environmental Security Technology Certification Program (ESTCP) is DoD's environmental technology demonstration and validation program. The Program was established in 1995 to promote the transfer of innovative technologies that have successfully established proof of concept to field or production use.
   http://www.serdp.org/About-SERDP-and-ESTCP/About-ESTCP

2. Jones, Dennis, Proceedings of the 1987 Annual Meeting, American Solar Energy Society, p 381.

3. Jones, Dennis, Proceedings of the 1989 Annual Meeting, American Solar Energy Society, p 99.

4. ASHRAE Handbook, 2001 Fundamentals, American Society of Heating Refrigerating and Air Conditioning Engineer, Atlanta, GA

Extended List of Findings and Results:

For many facility managers and design professionals, a snapshot of results and performance of one project is helpful in understanding the scope of the project and approaching the design of a new system. Toward that end, the following is a list of findings and results from the Gaffney Fitness Center Solar Air Heating Re-roof that will help the reader to quickly get a sense of the scope, performance, and economics of the solar air heating re-roof for Outdoor Air Preheat, Direct Space Heat, Solar Roof Heat Loss, and the Prediction of Solar Air Temperatures of Unglazed Solar Air Heating Roofs.

Findings: The following summarizes the findings with a focus on creating a predictive model of solar temperatures and its application to energy and economic predictions for similar systems:

1. The delivered solar air temperatures can be predicted with good precision for daily, monthly, and annual analysis using only local solar and weather data inputs.
2. The prediction is suitable for use with standard environmental data such as the typical meteorological year (TMY) data to generate weekly, monthly, and annual solar air temperatures for energy delivery.
3. The prediction of delivered solar air temperatures <u>for analysis of any specific hour</u> requires additional solar inputs to improve the accuracy of prediction at start up, shut down, and peak mid-day hours. Addition of hourly solar elevation data and outdoor temperature and other environmental elements (wind gusts, etc.) can improve the prediction for short term specific hourly modeling use.
4. The prediction of solar air temperature and operating hours can be applied to any similar system using TMY data and utility rates in order to establish the energy savings and economic benefits of installing other solar air heating metal roofs.

<u>Results:</u>

1. The solar air heating roof provided reliable solar heated air for outdoor air preheat during sunny to cloudy days over a 4 month period from October to January.
2. During the 109 day monitoring period, from October 12 to January 29, the solar roof provided solar heated air to the outdoor air intakes of the main air handler for the gym based on a call for heat from the central Building Automation System (BAS) and the temperature of the solar air.
3. Cold weather beginning November 6 brought a continuous call for heat by the gym central BAS. From 11/6 to 1/29 the system solar fans ran for 1448 hours or 18% of the time. This included all hours with positive natural gas heating energy savings, even if there were some marginal cost savings due to the electric cost to run the fans.
4. During the cold weather operating hours of the test period, the system supplied solar heated air that averaged 14F above outdoor ambient temperatures and peaked at 43F above outdoor air.
5. Based on modeled annual operations, the solar outdoor air preheating system, as it is installed, would operate for 749 hours, when the net cost savings (gas-electric) cost savings would be positive. During those hours, the system would supply 107 million BTU of heat to the outdoor air intakes whenever the outdoor air is below 52F and there is

a call for heating in the building. With a 90% efficient boiler, this saves 119 million BTU/year in natural gas.

6. Based on modeled projections for annual operations, as installed, when there is a call for heat, and solar fans turn on whenever 8.1F warmer than the outdoor air, the system would run for 1620 hours and deliver 162 million BTU of heat to the outdoor air intakes, savings 179 million BTU in natural gas at the boiler.
7. The solar roof keeps the old, covered over, built up roof (BUR) surface 18.6F warmer than the outside air temperature during the winter months from November thru April, averaging 60.7 F, when the exposed BUR would average 42.2F.
8. The winter heat flow reduction from the insulating value of the solar roof equals 21 million BTU, saving 23 million BTU in gas at the boiler.
9. The winter energy delivery for direct space heat to the gym is 41 million BTU with an average temperature of 92.8F operating for 550 hours whenever the solar temperature is above 78F. This saves 45 million BTU of natural gas at the boiler.
10. Total natural gas energy savings for the system 'as installed' is 188 million BTU/year using the existing turn ON (OAT+19F) and turn OFF (OAT+18F) temperatures, and accounting for direct space heat and reduced heat loss from added insulating value of the solar roof.
11. Total natural gas energy savings of 248 million BTU can be achieved with the system operating with a 8.1F TURN ON-OFF differential from outside air temperatures.
12. A multiple regression analysis of the solar air temperature using solar insolation, outdoor air temperature, and average wind speed and solar elevation, as independent variables, provides a predictive model of solar air temperature.
13. The model provides reliable prediction for use with weekly, monthly, or annual average modeling of solar temperatures, above outdoor air temperatures (OAT), where delta T above OAT is used for energy delivery calculations.
14. The simple model generally overestimates temperature in the earliest and latest hours of the day and under predicts during the few hours around solar noon for any particular day.
15. Use of regional outdoor air temperature data which is less likely to be affected by local building heating from walls and mechanical equipment provides a better model result than using local building outdoor air temperatures.
16. The system provides 25,827 BTU/sqft/yr in natural gas savings from outdoor air preheat, direct space heat, and reduced heat loss, when using a metric of 1 sqft/1 cfm of solar air flow (7,263 cfm actual flow). When using the total solar area of 9,275 square feet from all the roof zones feeding the fans, the installed system provides 20,224 BTU/sqft/yr.
17. With and ON-OFF differential of 8.1F, the system is capable of providing 34,201 BTU/sqft/yr using 7,263 sqft and 26,782 BTU/sqft/yr using 9,275 sqft.
18. During the winter months, the 'as installed' peak monthly heat flow for direct space heat and outside air preheat calculated during a typical meteorological year is 4,788 BTU/sqft, which occurs in March. With an 8.1F differential to OAT, the peak monthly heat flow would be 6,225 BTU/sqft.
19. During the winter months, the peak daily heat flow for outside air and direct space heat calculated during a typical meteorological year occurs on April 4th, and is 318 BTU/sqft/day. With an 8.1F differential, the system will deliver 350 BTU/sqft/day.
20. During the winter months, the calculated total peak hourly heat flow for outside air preheat and direct space heat is 47 BTU/hr/sqft, when using 5,320 sqft of roof from zones

3 & 4 and 60 BTU/hr/sqft when using 3,797 sqft to match the typical 1 cfm/sqft design. This peak heat flow occurs in early April, per the TMY calculation.

Appendix A-3 :Solar Roof Vs. Cool Roof,

Solar air heating roofs, impact on summer cooling loads

Executive Summary:

Background: American Solar, Inc. evaluated the impact of its solar air heating roof system on the summer cooling loads on the roof and the impact on air conditioning loads. This analysis is part of a larger project to document the overall annual energy and life cycle roofing benefits of a solar air heating roof.

The project is funded by the Department of Defense Environmental Security Technology Certification Program (ESTCP) (Ref. 1). The Solar roofed building is the Gaffney Fitness Center at Fort Meade, MD.

The following summarizes the analysis with a focus on addressing 3 issues:

1. The impact of a solar air heating roof on the Gaffney Building and the thermal loading on the building roof during the summer cooling season.
2. Comparison of the solar air heating roof to the performance of "cool roofs" which use reflective top coatings on the weather exposed roof surfaces.
3. Comparison of the small cooling energy cost savings from solar and non-solar roofing to the much larger roofing and heating energy cost savings for a solar air heating roof.

A series of temperature sensors were installed within and around the new solar roof. This included a set installed in a 'vertical' stack of the roof, from the top of the solar air space to the bottom of the existing roof deck. This vertical stack, and other spot infrared surface temperature readings on the solar roof and nearby non-solar roof, provide a comparison of roof temperatures, with and without the solar roof.

Results:

The Solar Air Heating Roof:

1. **Reduces the summer cooling load on the building,** by an estimated $83 per year.
2. Reduces peak electricity demand by cutting air conditioning load during the most expensive peak demand hours
3. Provides significant solar water heating capability during the cooling season including spring, summer, and fall
4. Reduces the combined building cooling load and domestic hot water heating load, by about 11 times more than the reduced energy load from the best 'cool roof' alone
5. Provides cooling cost savings that are about 1% of the total roofing, heating, and cooling savings.
6. Provides a very large space heating and outdoor air preheating capability during the fall, winter, and spring heating season
7. Provides a long life, weathertight roof.

Introduction:

The solar air heating roof retrofit on the Gaffney Fitness Center involved the installation of a black metal standing seam roof over a metal substructure with fiberglass and radiant barrier insulation. This retrofit was installed directly over the existing built up roof (BUR) which was on top of a polyisocyanurate (Polyiso) board insulation and corrugated metal deck. Inside the building, at the ceiling of the gym, a 3" thick fiberglass insulation with cloth jacket covered the bottom of the metal deck. See Figures A-3, 1-8.

Figure A-3, 1 Gaffney Aerial View

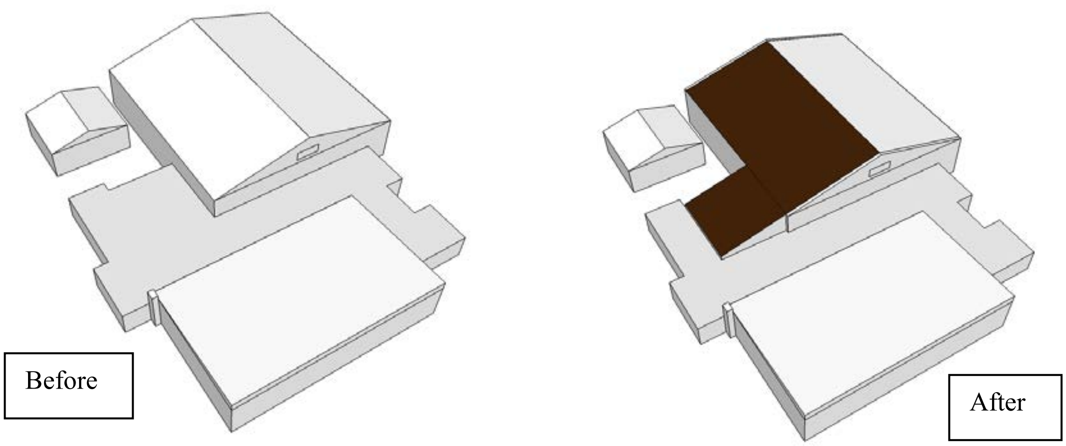


Figure A-3, 3 Before & After

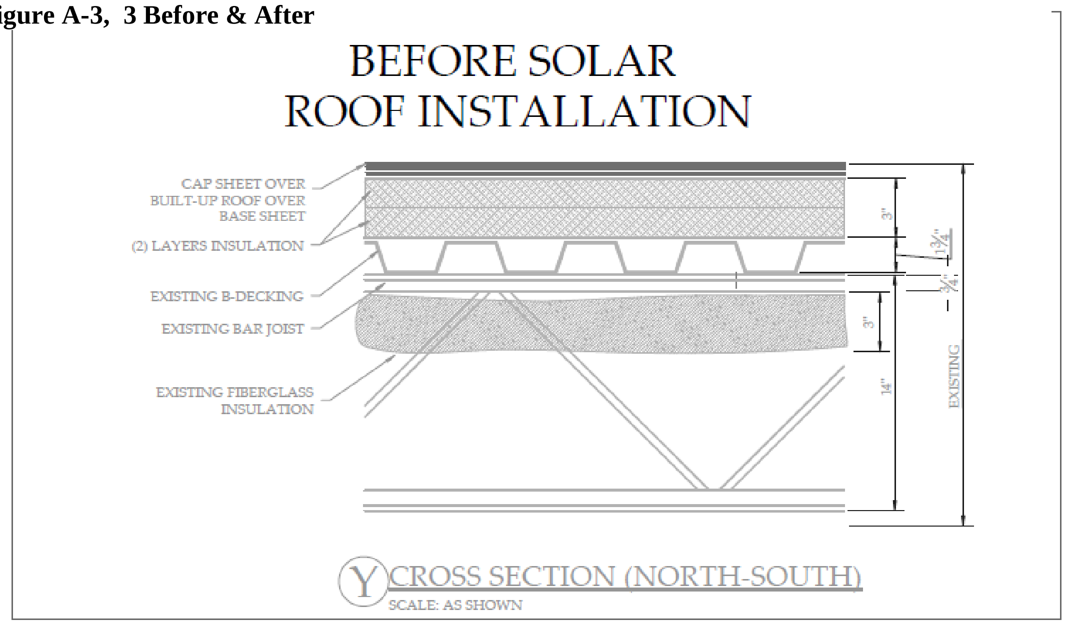
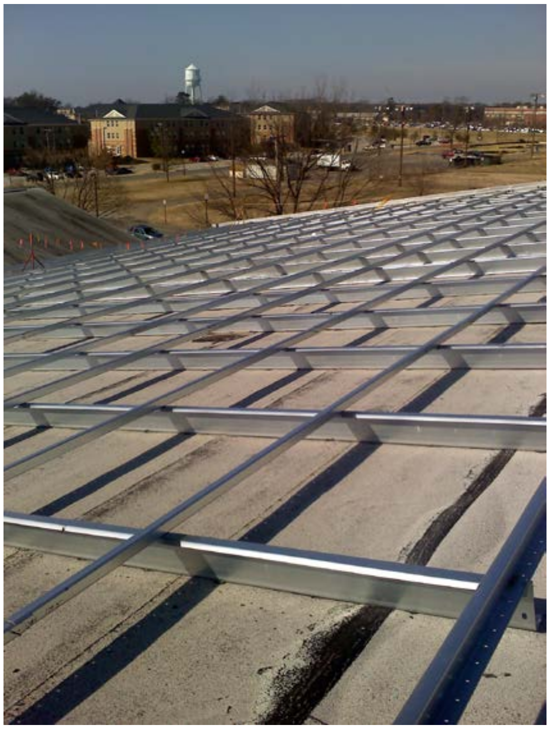


Figure A-3, 2 Roof Section, Before Solar

Figure A-3, 5 Old Sloped Built Up Roof on Gym

Figure A-3, 4 Gym Interior Ceiling



FigureA-3, 6 Solar Roof Support Structure on Gym Roof

Old Sloped Built Up Roof on Gym
Gym Interior Ceiling,
and
Solar Roof Support Structure on Gym Roof

Solar Roof Panels being installed over Fiberglass and Radiant Barrier Insulation and
As-Built Solar Roof Section Drawing

Figure A-3, 7 Solar Roof panel Installation Over Insulation

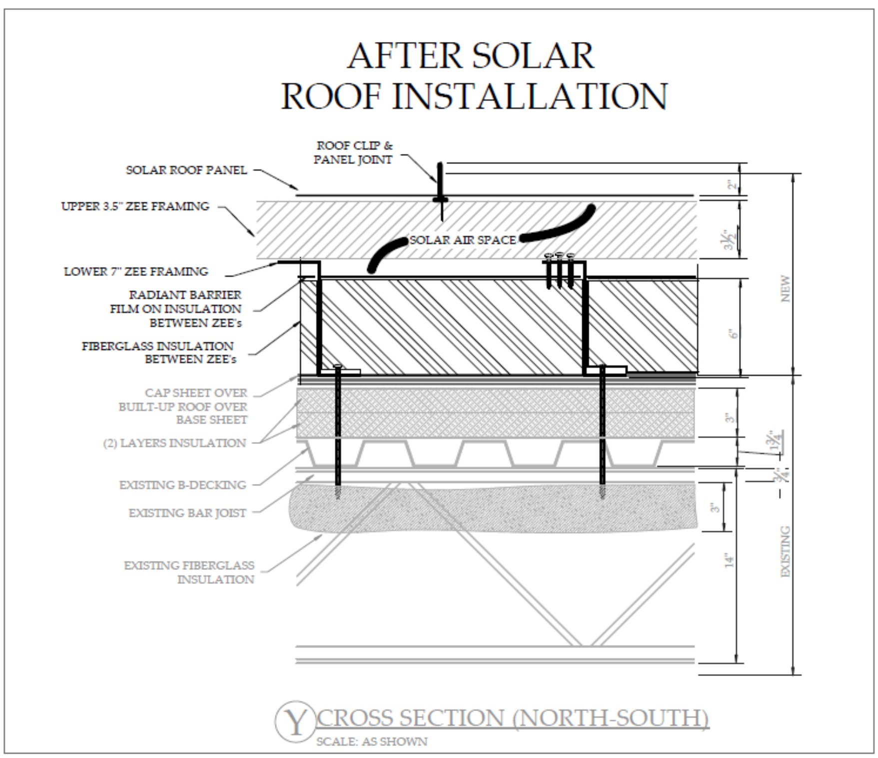


Figure A-3, 8 Roof Section, AS-Built

To document the thermal performance of the solar roof, temperature measurements were made with spot infrared thermometer readings of various surfaces and by data logging of temperatures with numerous, fixed 10k ohm thermistor sensors embedded in the solar roof and arranged at various locations in the solar ductwork and piping. The temperature and air and water flow measurements generate overall thermal performance of the roof and solar air-to-water heating system.

One common question asked by many interested parties is, “What is the impact on the building’s air conditioning load, of a hot solar roof surface above the building”. A second question that is often asked is, “How does the solar air heating roof compare to the cooling reduction of a reflective, ‘Cool Roof’?”

The data collected as part of this DOD ESTCP project was designed to answer those questions. The data enables a comparison of the solar and non-solar roof temperatures that drive the roof heat gains during the cooling season. Specifically, we compare the solar roof and the existing non-solar BUR, and we compare the solar roof to a ‘cool roof’.

During construction of the solar roof, several temperature sensors were placed at strategic locations within the roof. At one location, within 8’ of the ridge of the solar roof, sensors were placed in a vertical stack. See Figure A-3,9 -11; 1a] in the solar air space, 1b] immediately below the radiant barrier that rests on top of the fiberglass insulation, 1c] below the fiberglass insulation, resting directly on the old built up roof, and 1d] below the polyisocyanurate insulation layer, on top of the existing built up roof deck.

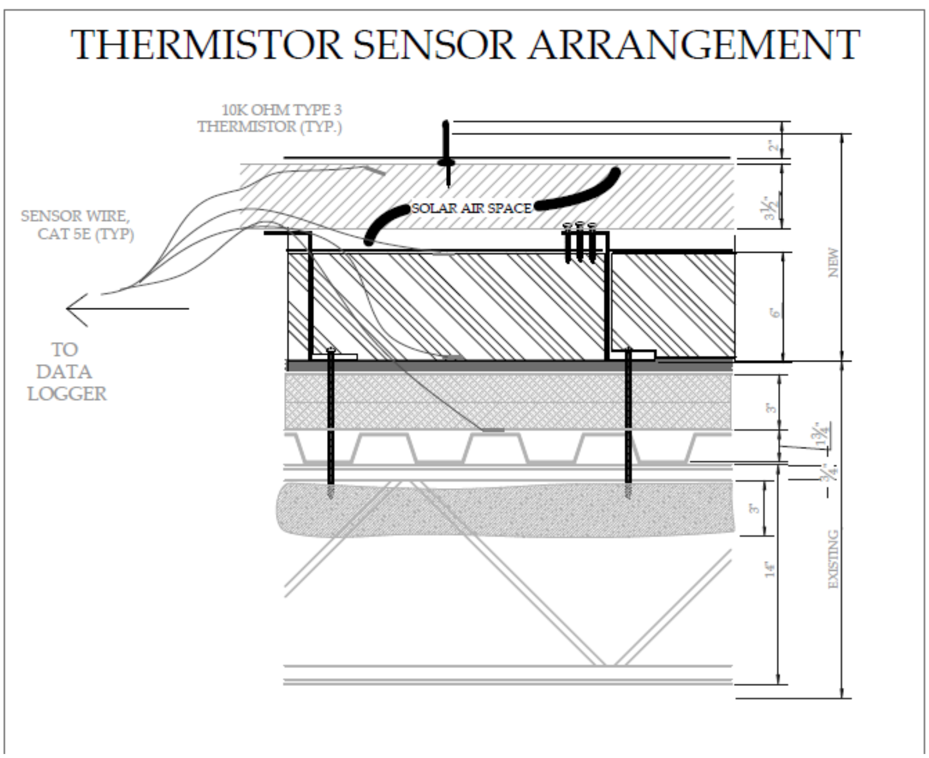


Figure A-3, 9 Thermistor Sensor Arrangement, Roof Section

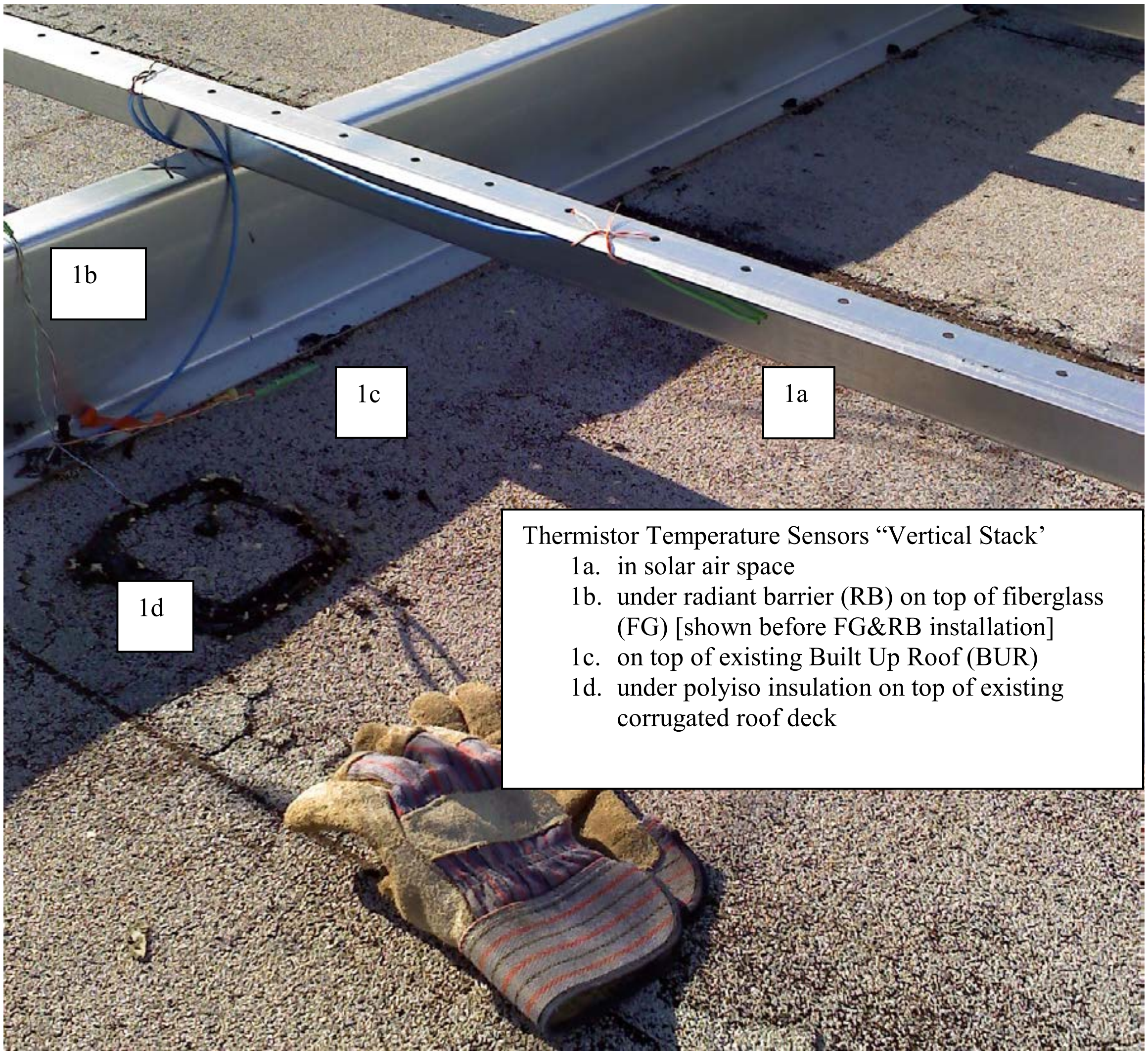


Figure A-3, 10 Thermistor Sensor Arrangement, Vertical Stack

During the early testing in late June, 2012, temperatures across the solar roof were recorded at 15 minute intervals at all these temperature sensors. During the daytime hours, the solar fans were running, drawing outdoor air from the ridge air inlets down through the solar air space to the outlet in the solar attic/mechanical space created below the eaves of the old gym roof.

In addition, on June 28, 2012, shortly before local noon (11:55 EDST, ~10:55 Solar time), a series of surface temperatures were taken using a hand held infrared (IR) thermometer. The surface temperatures were on the existing, exposed built up roof (BUR), the new built up roof flashing that ties in the old BUR to the new solar metal roof at the ridge, and at various locations on the field of the solar metal roof and the ridge. Additional IR measurements were taken inside the gym at the ceiling below the vertical stack of sensors, at the gym floor, and outside on a shaded target in air at 4' above ground level. See Figure A-3, 11 and table A-3, 1.

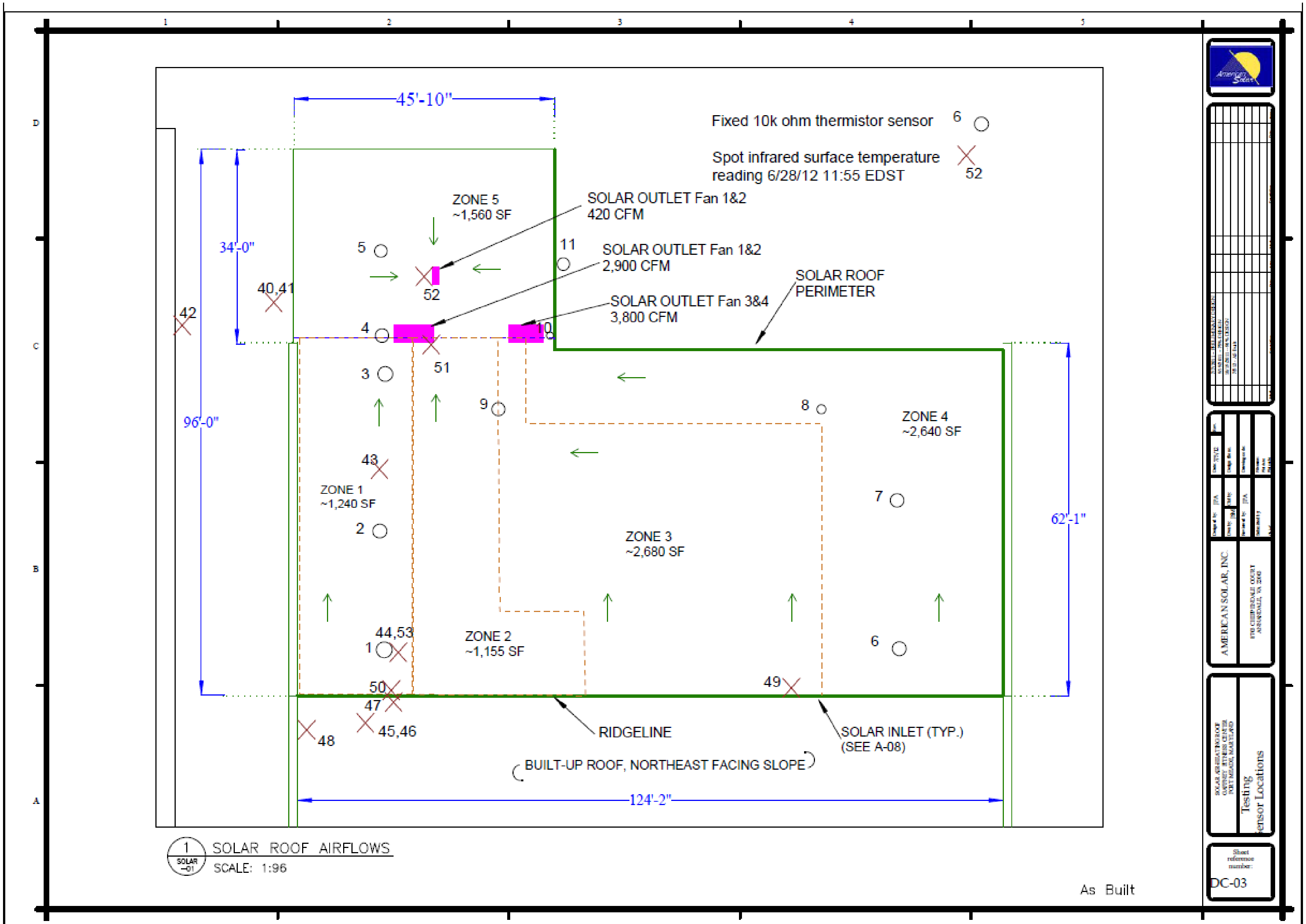


Figure A-3, 11 Thermistor and IR Temperature Reading Locations

Solar Roof Temperature Sensor and Spot Infrared Thermometer Locations		
10k ohm Thermistors, fixed sensors, data logging at 15 minute intervals		
Location	Description	Service
1	Zone 1 High	BUR stack, Solar Air
	1a	Hi, in solar air space
	1b	BUR Belo RB, Below radiant barrier, on top of fiberglass insulation
	1c	BUR Belo FG, Below fiberglass insulation, on top of old BUR
	1d	Belo ISO, Below polyiso insulation, above corrugated metal roof deck
2	Zone 1 mid	Solar Air
3	Zone 1 Low	Solar Air
4	Attic Air	Attic Air 8' above low slope roof BUR
5	Heat Exchanger	Water, Solar air
	5a	Solar air into HX, solar air to air-to-water heat exchanger
	5b	Solar air out of HX, solar air out of air-to-water heat exchanger
	5c	Solar h2o into HX, cold/preheat water to air-to-water heat exchanger
	5d	Solar h2o out of HX, solar preheated water out of air-to-water heat exchanger
6	Zone 4 High	Solar Air
7	Zone 4 Mid	Solar Air
8	Zone 4 Low West	Solar Air
9	Zone 4 Low East	Solar Air
10	Fan 3&4 Outlet	Solar Air
11	Outdoor Air	Outdoor Air
12	Cold City Water	Water into solar preheat loop
13	Return Water to Building	Solar preheated water into building water heating loop
IR thermometer, spot readings, 6/28/12 11:55 EDT		
40,41	Existing flat BUR in sun	BUR
	40	BUR with ~25-40% granules missing
	41	BUR with ~0-5% granules missing
42	Existing BUR Flashing in shade	BUR
43	Solar center of Zone 1	Solar Roof
44	Solar Zone 1 Hi above BUR	Solar Roof, above the vertical stack sensors 1a-1d
45,46	Existing North BUR in sun	BUR
	45	BUR with ~20-30% granules missing
	46	BUR with ~10-20% granules missing
47	New BUR Flashing in sun	BUR
48	Existing BUR Flashing in shade	BUR
49	Zone 3 Solar Ridge	Solar Roof
50	Zone 1 Solar Ridge	Solar Roof
51	Zone 1 Plenum	Solar Roof
52	Zone 5 Plenum	Solar Roof
IR thermometer, spot readings, 6/28/12 12:50 EDT		
53	Gym interior ceiling below BUR Stack	Gym Ceiling
54	Gym Floor below BUR stack	Gym Floor
55	Outdoor air in shade	Outdoor shade

Table A-3, 1 Solar Roof Sensor and IR Locations

Figure A-3, 12 shows the temperatures of the different sensors in the 'vertical stack' of the roof over a one day period.

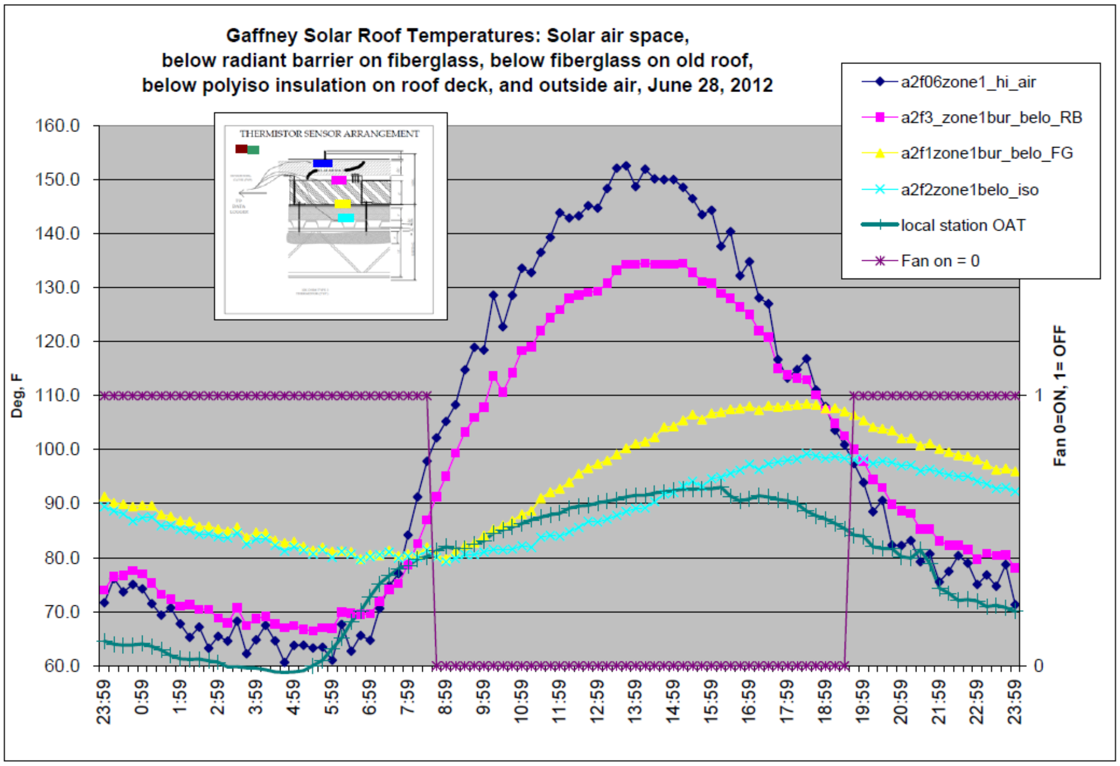


Figure A-3, 12 Solar Roof Temperatures Vertical Slice

During this 24 hour period, the solar fans for zones 1&2 ran from 8:30 to 19:45, 11 hours and 15 minutes. They pulled solar air in from the ridge down the slope of the solar roof to the solar mechanical space where the solar heated air was used to preheat domestic hot water. The fans turn on when the solar roof air is 8 F warmer than the water to be heated and turn off when the solar air is less that 4 F warmer than the water being heated.

In Figure A-3, 13, a vertical line with several circles and ovals is shown at 11:55 local daylight savings time. This is when the surface spot IR temperature readings were taken around the roof.

At the vertical line on the chart, the outdoor air temperature, from two local weather stations indicated an outdoor air temperature (local station OAT) of 88F.

A surface IR temperature at location 44, shown as circle 3 on the chart, indicated the solar metal roof surface temperature was 143F. This is consistent with the temperature of solar air of 144F as measured by fixed sensor #1a (a2f06zone1_hi_air) in the solar air space below the metal roof panel and above the radiant barrier insulation.

Sensor #1b (a2f3_zone1bur_belo_RB) is placed just below the radiant barrier and rests on top of the 6" fiberglass blanket insulation. Temperature below the radiant barrier was 126F, 18 degrees cooler than the roof panel/solar air. As discussed later, the radiant barrier will typically lower the air temperature below the barrier by 20F.

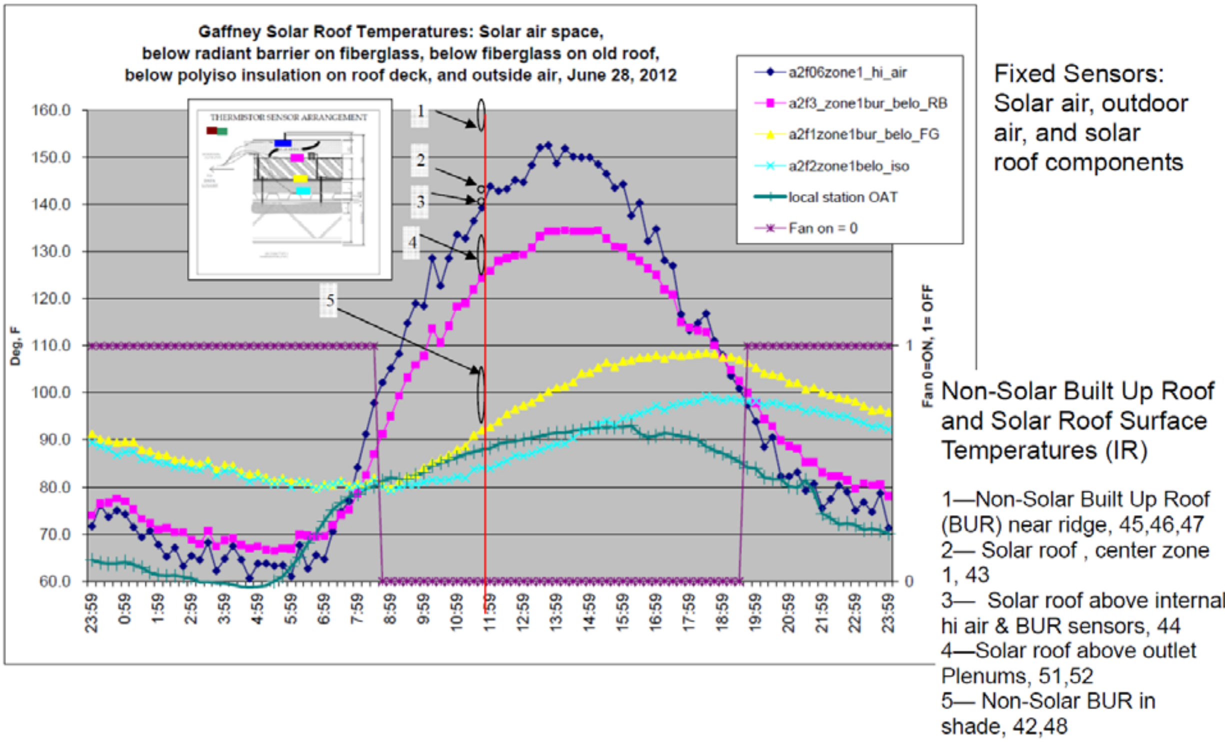


Figure A-3, 13 Solar Roof Temperatures with IR, Vertical Slice

Another sensor, #1c, (a2f1zone1bur_belo_FG) is installed on top of the old built up roof, below the fiberglass blanket. This sensor measures the temperature of the old BUR surface and was

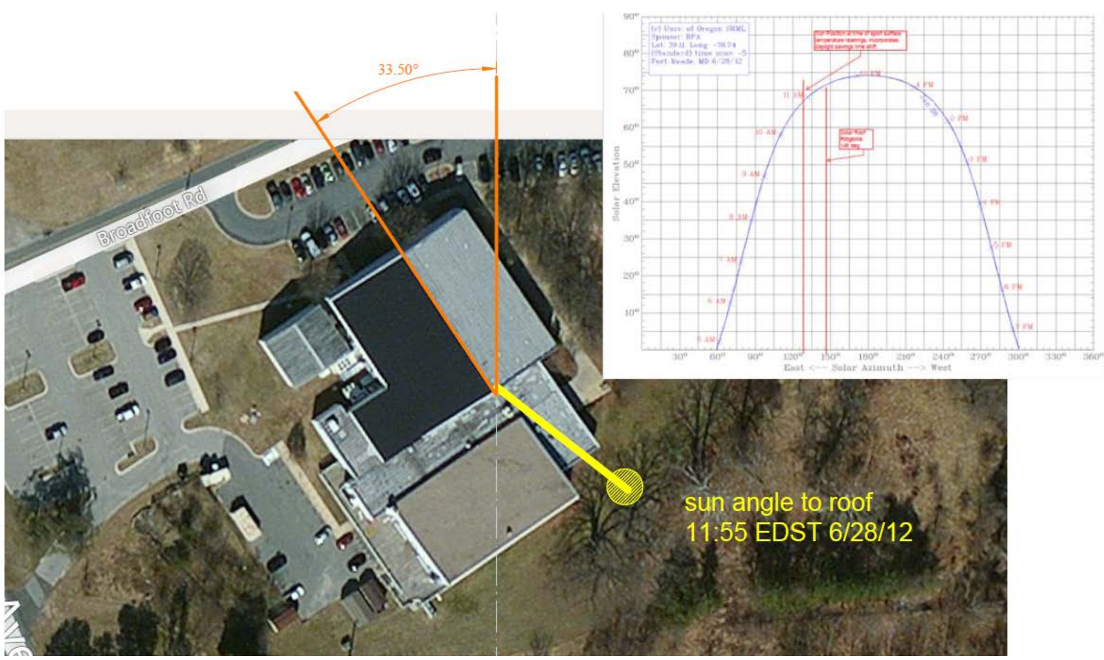


Figure A-3, 14 Solar Orientation During Test

93F. As discussed later, this temperature is the most important in comparing a solar air heating roof's cooling performance to that of a conventional, or 'cool' roof.

A final sensor of this grouping, #1d, (a2f2zone1belo_iso) is installed below the polyisocyanurate insulation boards that sit on the corrugated roof deck. The temperature at this location was 84F.

An IR surface temperature was taken of the interior face of the fiberglass insulation that is the ceiling of the gym, below the corrugated roof deck. The location of the ceiling temperature was directly below the sensors in the 'vertical stack' of the roof above. The surface temperature of the ceiling was 72F. The temperature at the floor of the gym was 67F.

The other circles and ovals at time 11:55 show various IR surface temperature readings. Of interest to this discussion related to solar roofing vs. 'cool roofing, is the oval marked '1' at the temperature range of 166-154F. These surface temperatures were on the BUR and BUR flashing just to the north of the solar roof in locations 45, 46, and 47. Location 45 and 46 are taken about 8' from the northeast side of the solar roof ridge, in a location comparable to the BUR vertical stack of sensors in the solar roof on the southwest side of the ridge at location #1, #44.

At the time of the IR temperature readings, the sun was at an elevation of 68 degrees and just 19 degrees north of the ridge line, providing essentially equal heating of the solar and non-solar portions of the Gym room. (Figure A-3, 14).

Four Reasons for a Cool Solar Roof

There are four phenomena that keep the BUR under the solar metal roof cooler than the exposed BUR. First is the shading of the solar BUR surface by the metal panel. Second, is the reflection of radiated heat from the panel by the radiant barrier. Third, is the movement of solar air below the panel which cools the panel. Fourth, is the insulation of the Solar BUR from the hot air stream by the fiberglass insulation.

In several solar air heating projects, American Solar has measured a 10-20F temperature difference between the air above a radiant barrier and the air below. The combination of the reflection of the radiant heat back up toward the roof panel and the physical air barrier that helps stratify the warmest air above the radiant barrier, keeps the air below about 10-20F cooler during most daylight hours.

For most solar heating roofs, the roof panel will hit about 70-80F above outdoor air temperatures, when there is no air flow. With normal solar air flow, the solar air temperature in the roof will drop to about 40F above outside air temperatures.

The fiberglass insulation that separates the air below the radiant barrier from the BUR below, has a moderating effect on the temperature of the BUR. It slows the heat transfer down to the BUR and it delays the temperature rise over the course of several hours. So a peak temperature at the BUR at 18:00 is 4 hours later than the peak temperature below the radiant barrier at 14:00 that caused it.

<u>Solar roof vs. existing white BUR</u>

What is informative is that the temperature of the existing and new white BUR at 45, 46, 47, sitting directly on the polyiso insulation is 10-22 degrees F warmer than the black solar metal roof or the solar air moving under the solar roof. Even more informative, is that fact that the existing exposed BUR at location 45 (160F) and 46 (154F, Figure A-3,15) is 61-67F hotter than the covered BUR at #1, #44 (93F) under the 'hot', black, solar metal roof.

Figure A-3, 15 IR Surface Spot Temperature

The combination of the moving solar air, the radiant barrier, and the fiberglass insulation, that separate the hot solar roof panel from the old BUR below, keep the covered BUR cooler than the exposed, non-solar BUR during the peak daytime cooling hours. (See previous sidebar) Even with the delayed heating of the BUR under the solar roof it never reaches a value greater than 109F (at 18:30). This delayed peak temperature is still 45-51F cooler than the peak temperature of the exposed BUR sitting above the non-solar roof at 11:55.

When compared to the interior surface temperature (72F) of the gym fiberglass ceiling insulation, the exposed, non-solar BUR is as much as 88F hotter then the interior ceiling surface, which is less than 9 inches away. In comparison the BUR under the solar roof is only 21F hotter than the interior ceiling surface, at 11:55 and only 26 degrees warmer at its peak at 18:30 than the gym ceiling temperature.

This substantial reduction in the temperature difference between the ceiling and the cooler BUR under the solar roof, vs. the hotter non-solar BUR represents a significant reduction in the roof heating load on the building.

We calculate this heating load using the methodology in the ASHRAE Fundamentals, 2001 (Ref. 2) which combines the thermal resistance, 'R' values of the components between the top of the BUR and the bottom of the ceiling surface. The individual components have R values as shown in the Table A-3,2. The total R value of the assembly from the top of the BUR to the inside of the ceiling insulation is 36.

Component	R value
BUR	.33
Polyiso Insulation	24
Air Space in corrugated deck	.91
Fiberglass ceiling insulation	11

Table A-3, 2 Solar Roof R-Values

Using this R value, the hourly heat flow through the solar and non-solar roofs was calculated. (Table A-3, 3) Across the entire 7,715 square feet of solar roof in Zones 1 thru 4, this represents a difference of 14,263 BTU/hr. That is equivalent to the capacity of a 1.2 ton air conditioner.

Heat flow from **Solar roof** covered BUR to ceiling interior surface	
0.58	BTU/hr/sqft @ 21 F delta T
4,471	BTU/hour heating of gym from solar roof zones 1-4
Heat flow from **exposed, Non-solar BUR** to ceiling interior surface	
2.43	BTU/hr/sqft @ 88 F delta T
18,734	BTU/hour heating of gym from solar roof zones 1-4

Table A-3, 3 Heat Flow Through Gym BUR

Over the course of this one day, the average temperature difference between the Solar roof BUR and the Gym ceiling is 15.5F. If we assume, conservatively, that the non-solar BUR temperature is just equal to the solar roof air temperature, then the average temperature difference between the non-solar BUR and the Gym ceiling is 26.9F.

Over the course of this one day, 6/28/12, when heat loads are calculated based on hourly temperature differences, the solar roof reduces the heat load by 41,800 BTU/day compared to the existing white BUR. This one day represented 11 cooling degree days, using a 65F degree base. There are an annual total of 1137 cooling degree days for Fort Meade (Baltimore).

So, the total annual cooling savings for the solar roof vs. the white BUR would be 4.3 million BTU per year. See Table A-3,4 for a summary.

(Note: on the Gaffney Building there are additional cooling savings that accrue from the 1,560 square feet of solar roof area over the flat roof. See the Addendum at the end of this appendix for a discussion of the savings from that area.)

Comparison Solar vs. Existing BUR	Solar Roof Cooling Energy Savings [BTU] + solar roof net savings ( ) 'cool' roof net savings	Solar Roof Cooling Cost Savings [$] + solar roof saves ( ) 'cool' roof saves
Solar BUR vs. Existing BUR [using Gaffney hourly temperature difference calculation]		
Solar BUR vs. Existing BUR	14,263/hour [@ 11:55 6/28/12] 41,799/day [6/28/12] 4.3 million/yr	$0.18/hr for kwhr consumption [@ 11:55 6/28/12] $66.96 per year kwhr consumption $3.10/mo. for peak KW demand $15.60/yr. for peak KW demand $82.56/yr total cooling savings

Table A-3, 4 Solar vs. Existing BUR, Energy & Cost Savings

<u>Solar Roof vs. 'Cool' Roof</u>

To compare the solar roof to a 'cool' roof we can use two techniques. The first technique (referred to as 'Method 1') uses the Department of Energy CoolCalcPeak program, which calculates the energy savings of roofs with different reflectivity. The second technique compares the Gaffney roof test results to measured test results from Oak Ridge National Lab (ORNL) black and white roof membranes.

The DOE CoolCalcPeak program is used to estimate cool roofing benefits compared to a "baseline" black roof. This represents the best/worst comparison for cooling savings from a re-roofing, where an existing roof is black and a new roof would be highly reflective white. To compare two 'non-black' roofs to one another requires two computer runs, one for each roof against the black roof, then comparing the differences in results. For example, white roof with 85% reflectivity vs. black gives 'X' savings per sqft/yr and an 'off white, 50% reflective roof gives 'Y' savings per sqft/yr. So, using 85% vs. 50% give savings equal to ('X' – 'Y') per sqft/yr.

Using this approach, the annual cooling load savings between the most reflective ‘cool’ roof (85% reflectivity) and the black roof (5% reflectivity) would be 1116 BTU/sqft/year. For the 7,715 sq ft Gaffney surface this would be 8.6 million BTU/year, *compared to a black original roof*.

However, because the existing Gaffney roof has white roof granules over a black asphalt substrate, creating a near-white surface, the CoolCalcPeak program instructions recommend estimating a reflectivity of the existing roof, then comparing the cooling energy savings between the two CoolCalcPeak runs to estimate the difference. In essence, the cooling savings for the existing white Gaffney roof = [(savings high reflect – black) – (savings existing white – black)]. We assume a 50% reflectivity for the existing Gaffney white BUR (See Figure A-3,16) and we calculate 251 BTU/sqft/yr vs. black, or 1.9 million BTU/yr.

So, using this Method 1 approach, the CoolCalcPeak savings difference between an 85% reflective roof and the existing white BUR would be 6.7 million BTU/year (~8.6-1.9). See Table A-3, 5 for a summary.

Comparisons Cool Roof vs. Existing BUR	Solar Roof Cooling Energy Savings [BTU] + solar roof net savings ( ) ‘cool’ roof net savings	Solar Roof Cooling Cost Savings [$] + solar roof saves ( ) ‘cool’ roof saves
‘Cool’ Roof vs. Existing BUR [Method 1, using CoolCalcPeak calculator]		
85% reflective ‘Cool’ roof vs. Existing BUR [~ 50% reflective]	(6.7) million/yr [savings for ‘cool’ roof vs. existing BUR]	($0.008)/sqft/yr for kwhr consumption ($61.72)/year [total kwhr & KW demand savings for ‘cool’ roof vs. existing BUR] ($.001)/sqft/yr peak KW demand ($7.72)/yr peak KW demand ($69.44)/yr total cooling savings

Table A-3, 5 Cool Roof vs. Existing BUR, Energy & Cost Savings

With the ‘baseline of the existing BUR’ compared to the Solar Roof and to a Cool Roof using the two previous examples, we can compare the savings between the two, in order to evaluate a Solar Roof vs. a Cool Roof. The 6.7 million BTU/year for a highly reflective cool roof vs. existing white BUR is reasonably close to the 4.3 million BTU/year calculated by the Solar vs. BUR temperature difference above. The difference of 2.4 million BTU/year translates to less than 2 BTU/sqft/yr. This indicates that the solar roof cooling savings are reasonably close to the

Figure A-3, 16 IR Surface Spot Temperature

savings from a retrofit of the best performing 'cool roof'.

The second technique to compare the solar roof to a "Cool Roof" (referred to as 'Method 2') is to compare the temperature of the solar roof BUR to the 'measured' temperature of a cool roof BUR/membrane. To do that we refer to a study by Dejarlais et al from Oak Ridge National Lab (Ref. 4), which compared the temperature of low slope membrane roofs, tested in July 2004. The paper gives hourly temperatures of white and black membrane roofs over a 24 hour period. See Figure A-3, 17. These temperature profiles are 'similar' to those shown on the Gaffney Roof. The black membrane (Bare black) has a temperature rise beginning at 0700 and peaking at 173F at 1430 and dropping back to 67F at 2200. The white membrane (Bare white) has a temperature following the same timeline, but with a peak temperature at 119F at 1430. Other tests in the chart show ballasted roof temperatures which are different from the Gaffney roof and not applicable.

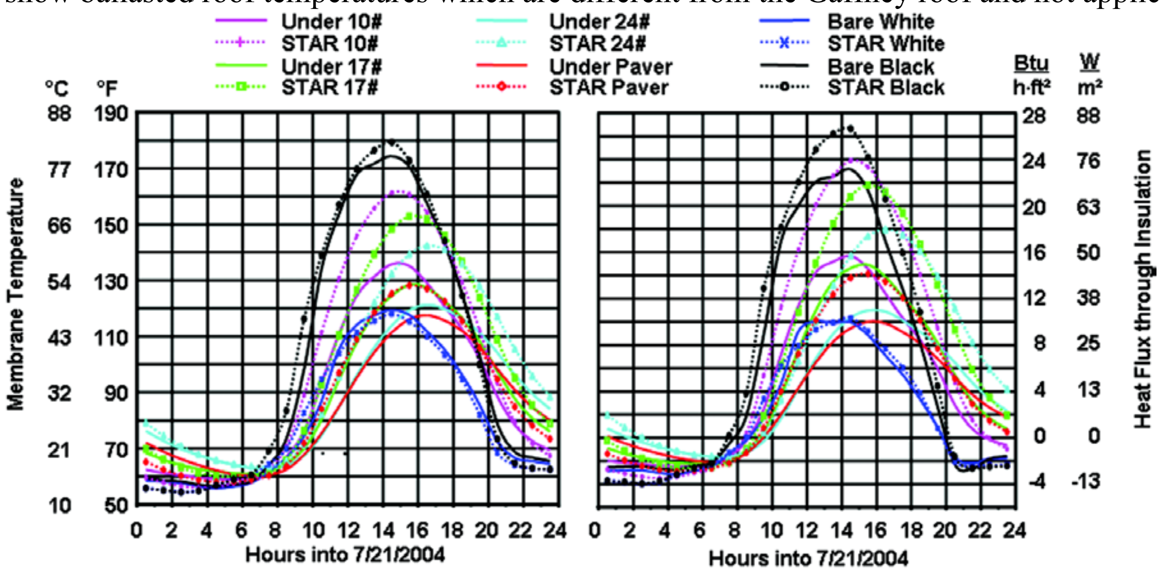


Figure A-3, 17 ORNL Black & Cool Roof Temps

The graph below, Figure A-3,18, shows the ORNL white and black roofs plotted with the Gaffney roof temperatures of 6/28/12. The oval at 160F, 11:55 is the IR spot temperature for the weathered, Non-Solar, BUR near the Gaffney ridge at location: 45, 46, 47 and is shown for reference on the graph and in the photo in Figure A-3,16.

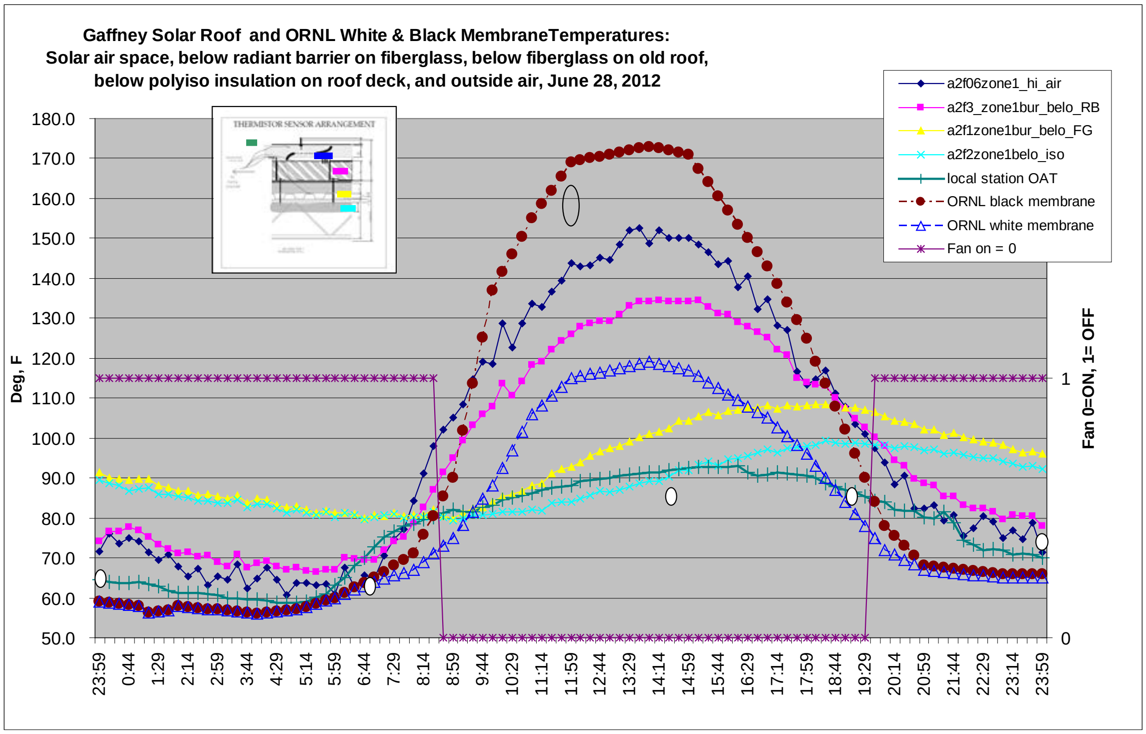


Figure A-3, 18 Solar & ORNL Cool Roof Temps

A check of the local weather confirms that the ORNL tests were conducted in similar weather to the Gaffney tests of 6/28/12. The white circles show several outdoor air temperatures of the ORNL test generally following the Gaffney OAT line. Given the similar conditions, we can assume that the Gaffney and ORNL roofs were tested on 'equivalent' days.

The ORNL roofs have reflectivity of 70% for white and 8% for black. One difference between the ORNL roof and the Gaffney roof is that the ORNL roofs are on 1.5" fiberboard over a corrugated roof deck. So the total R value of ORNL roofs is 5. The Gaffney roof has a total R value of 36. The higher R value of the Gaffney roof slows the temperature rise at the Gym ceiling during the solar heating hours and slows the temperature drop at the ceiling during nighttime cooling hours. So the ORNL roofs with lower insulation, cool quicker at night and reach lower nighttime temperatures than the Gaffney roof.

However, using this equivalency of weather and surface temperatures, we can draw a few conclusions about the solar roof vs. the ORNL 'cool' white roof. First, the ORNL 'cool' white roof reaches hotter surface temperatures during the daytime hours than the covered BUR under the solar roof. At noon, the 'cool' white roof is actually 22F warmer than the covered BUR under the solar roof.

The ORNL 'cool' white roof is hotter during the "peak cooling" hours, during which electric rates from the local utility, BG&E, are highest, at $0.104/kwhr. The BG&E summer peak rate is based on a 10 hour peak period which begins at 10:00 and ends at 20:00 and is twice as expensive as the remaining rates of the day. During that period, the 'cool' white roof averages 4F warmer than the BUR under the solar roof. During the intermediate peak hours ($0.055/kwhr) from 7:00 to 10:00 and 20:00 to 23:00 the cool white roof averages 22F cooler.

During the off peak hours from 23:00 to 7:00 ($0.048/kwhr), the cool white roof averages 28F cooler than the BUR under the solar roof. (The 22F and 28F cooler roofs during the intermediate and off peak hours are likely overestimated, i.e. too cool, given the rapid cooling of the lightly insulated ORNL roof, which leads to deeper cooling over time than a roof like the Gaffney roof, which has a conventional insulation thickness and R value).

For each hour, the heat transfer through the gym roof is calculated using the temperature difference between the ORNL cool white membrane roof surface and the ceiling, and between the BUR under the solar roof and the ceiling. Where the cool white or solar BUR surface is cooler than the ceiling, no cooling is credited, although there could be some benefit in sub-cooling the gym below the 73F temperature during night time hours with a cooler roof.

During the course of one day, the 'cool' white roof generates a heating load on the 7,715 square foot gym roof of 70,000 BTU. 64,000 BTU of this load occurs during the most expensive peak hours. By comparison, the BUR under the solar roof, generates a heating load of 108,000 Btu per day, but only 61,000 during the expensive peak hours.

So, using the Method 2 calculation approach, the difference between the 'cool' white roof and the solar roof is 38,000 BTU per day in favor of the 70% reflective cool roof, but 9,000 BTU/hr during peak hours in favor of the solar roof. Table A-3,6 summarizes the Method 2 comparison.

Comparison Solar vs. Cool Roof Method 2	Solar Roof Cooling Energy Savings [BTU] + solar roof net savings ( ) 'cool' roof net savings	Solar Roof Cooling Cost Savings [$] + solar roof saves ( ) 'cool' roof saves
Solar BUR vs. 'Cool' Roof **[Method 2, using Gaffney & ORNL temperature difference calculation]**		
Solar BUR vs. ORNL 'Cool' White Membrane [70% reflective, R value 5.0]	(38,000)/day [6/28/12] 3,000/[10 peak hours] (3.9 million)/ year	$0.03/[10 peak hours] ($0.20)/day [6/28/12] ($20.00)/year ($0.003)/sqft/yr

Table A-3, 6 Solar vs. Cool Roof Energy & Cost Savings

A summary of the three different comparisons is shown below in Table A-3,7.

Comparisons 1. Solar vs. Existing BUR 2. Solar vs. Cool Roof Method 1 3. Solar vs. Cool Roof Method 2	Solar Roof Cooling Energy Savings [BTU] + solar roof net savings ( ) 'cool' roof net savings	Solar Roof Cooling Cost Savings [$] + solar roof saves ( ) 'cool' roof saves
Solar BUR vs. Existing BUR [using Gaffney hourly temperature difference calculation]		
Solar BUR vs. Existing BUR	14,263/hour [@ 11:55 6/28/12] 41,799/day [6/28/12] 4.3 million/yr	$0.18/hr for kwhr consumption [@ 11:55 6/28/12] $66.96 per year kwhr consumption $3.10/mo. for peak KW demand $15.60/yr. for peak KW demand $82.56/yr total cooling savings
'Cool' Roof vs. Existing BUR [Method 1, using CoolCalcPeak calculator]		
85% reflective 'Cool' roof vs. Existing BUR [~ 50% reflective]	6.7 million/yr [savings for 'cool' roof vs. existing BUR]	$0.008/sqft/yr for kwhr consumption $61.72/year [total kwhr & KW demand savings for 'cool' roof vs. existing BUR] $.001/sqft/yr peak KW demand $7.72/yr peak KW demand $69.44/yr total cooling savings
Solar BUR vs. 'Cool' Roof [Method 2, using Gaffney & ORNL temperature difference calculation]		
Solar BUR vs. ORNL 'Cool' White Membrane [70% reflective, R value 5.0]	(38,000)/day [6/28/12] 3,000/[10 peak hours] (3.9 million)/ year	$0.03/[10 peak hours] ($0.20)/day [6/28/12] ($20.00)/year ($0.003)/sqft/yr

Table A-3, 7 Solar vs. Other Roofs, Energy & Cost Savings

Electricity Savings

To estimate the electricity savings from a reduced roof heating load, we assume an air conditioner with a high coefficient of performance of 2.5, producing 2.5 units of cooling energy for every 1 unit of electric energy consumed. Referring to the original temperature difference calculation for the solar roof vs. the existing BUR, the 14,263 BTU/hr of heat removed from the hot roof at 11:55 would require 1.2 tons of additional air conditioning per hour to remove the heat generated by the non-solar BUR compared to the BUR under the solar roof. This would require, 1.7 Kwhr of electric energy to run the air conditioning to cool the 7,715 square feet of non-solar BUR compared to the BUR under the solar roof.

Cost Savings

As discussed above, the 1.7 Kwhr of electric energy would be required to cool the non-solar BUR compared to the BUR under the solar roof.

Using the BG&E electric rates, during peak hours that would cost $0.18 per hour (at 11:55, 6/28/12) for Kwhrs consumed and $3.10/month for the higher KW demand during peak hours.

Table A-3,8 below summarizes the energy and cost savings that result using the 3 different approaches evaluated for the BUR under the Solar roof (Solar BUR) vs. the existing, exposed, non-solar, BUR and for the Solar BUR vs. an exposed 'cool' white roof.

Comparisons Solar vs. Existing BUR Solar vs. Cool Roof Method 1 Solar vs. Coo Roof Method 2	Solar Roof Cooling Energy Savings [BTU] + solar roof net savings ( ) 'cool' roof net savings	Solar Roof Cooling Cost Savings [$] + solar roof saves ( ) 'cool' roof saves
Solar BUR vs. Existing BUR [using Gaffney hourly temperature difference calculation]		
Solar BUR vs. Existing BUR	14,263/hour [@ 11:55 6/28/12] 41,799/day [6/28/12] 4.3 million/yr	$0.18/hr for kwhr consumption [@ 11:55 6/28/12] $66.96 per year kwhr consumption $3.10/mo. for peak KW demand $15.60/yr. for peak KW demand $82.56/yr total cooling savings
'Cool' Roof vs. Existing BUR [Method 1, using CoolCalcPeak calculator]		
85% reflective 'Cool' roof vs. Existing BUR [~ 50% reflective]	6.7 million/yr [savings for 'cool' roof vs. existing BUR]	$0.008/sqft/yr for kwhr consumption $61.72/year [total kwhr & KW demand savings for 'cool' roof vs. existing BUR] $.001/sqft/yr peak KW demand $7.72/yr peak KW demand $69.44/yr total cooling savings
Solar BUR vs. 'Cool' Roof [Method 2, using Gaffney & ORNL temperature difference calculation]		
Solar BUR vs. ORNL 'Cool' White Membrane [70% reflective, R value 5.0]	(38,000)/day [6/28/12] 3,000/[10 peak hours] (3.9 million)/ year	$0.03/[10 peak hours] ($0.20)/day [6/28/12] ($20.00)/year ($0.003)/sqft/yr

Table A-3, 8 Solar vs. Other Roofs, Energy & Cost Savings

Referring to the table, the Solar roof cut cooling energy use by 14,263 BTU/hour at 11:55 on 6/28/12. That translates into $0.18 per hour for kwhrs not consumed and $3.10 per month for reduced KW demand. Over the course of a year the solar roof saves ~6 million BTU in cooling energy with cooling cost savings of $82.56 per year.

The CoolCalcPeak program is used to predict the cooling savings of a highly reflective 'cool' roof compared to the existing ~50% reflective (est.) BUR on the Gaffney roof. The program predicts about 6.7 million BTU/ year in cooling savings would be gained by installing a highly reflective roof, with cooling cost savings of $69.44 per year.

A comparison of the solar roof to a 70% reflective 'cool' white roof measured under 'similar' weather conditions shows a very slight cooling savings for the cool white roof equal to $0.003 (3/10ths of a cent) per square foot per year or $20 per year for the 7,715 square foot Gaffney roof. However, the cooling savings for the 'cool' roof are likely overestimated compared to the Gaffney roof, as the ORNL 'cool' roof had a lower insulation value than the Gaffney solar roof, which improves the 'cool' roof's off peak cooling. Either with or without the cool roof's enhanced performance, the difference in cooling savings between the solar roof and the cool roof is insignificant.

Cooling Savings vs. Total Roof and Heating Savings

The solar roof is designed to do much more than provide a cooler roof for the building. In fact, its three primary purposes are to 1) provide low life cycle cost, high performance weathertight roofing and 2) deliver heat to the building for space heating and water heating and 3) increase the insulating value of the roof to resist winter heat loss.

The long life metal re-roof of the Gaffney Gym will likely save $0.22 per square foot per year in roofing costs compared to continued re-roofing with a built up roof. Total annual roofing savings would be $2,040/year for the 9,275 square foot roof. See Figure A-3,19.

During the one day period of 6/28/12, the solar roof was delivering hot water to the building's domestic hot water system. The roof was delivering hot water at about 25,000 BTU/hour, with a daily value of about 190,000 BTU/day, Annual calculations indicate savings of $1,338/year.

During the winter months, the solar heat will be used to heat the gym and is estimated to provide heating savings, valued at $1,569 per year from direct space heat and outdoor air preheat. An additional $273 per year is estimated for savings from reduced heating demand due to the added insulating value of the solar roof.

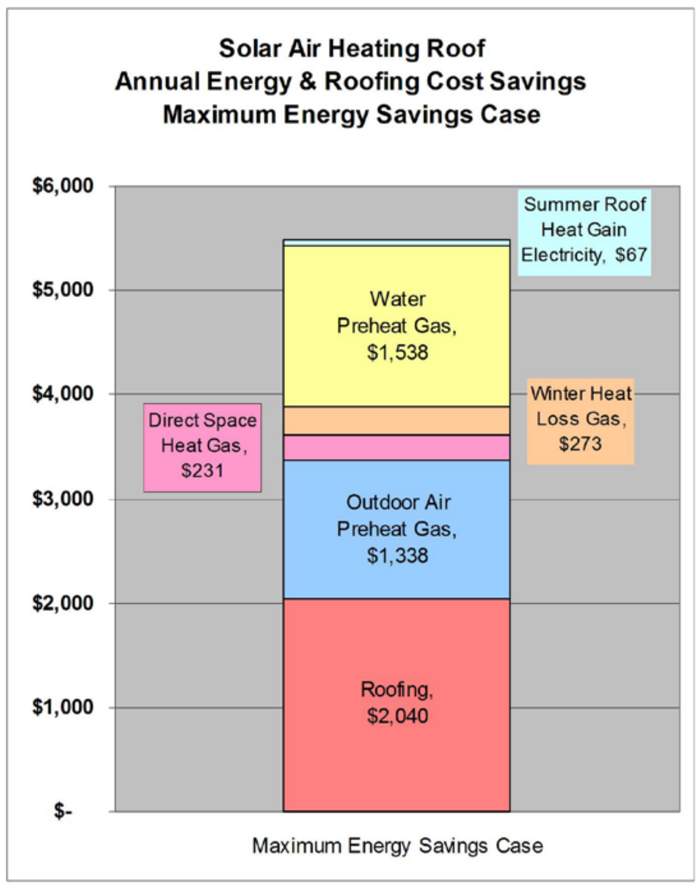


Figure A-3, 19 Solar Roof Annual Energy & Roof Cost Savings

So, total roofing and heating energy savings will be $5,420/year. The expected cooling savings of $67 per year amount to 1% of the combined $5,487 roofing, heating, and cooling savings from the roof. In comparison, if a highly reflective 'cool' roof were installed instead of a solar roof, the Government would lose all the heating and roofing savings and gain only about $69 per year in cooling savings.

Summary

The chart above shows the estimated cooling energy savings relative to the total expected savings from the Gaffney Solar roof.

An important item to take away from the analysis and the chart above is that the 'hot' solar roof actually contributes to cooling energy savings of about $67 per year.

These savings are a small percentage (~1%) compared to the total savings from roofing, space heating, and hot water heating that the solar roof will provide.

However, the measured data from the Gaffney Solar Roof confirms that the solar roof is actually reducing the summer cooling load in the building compared to the existing built up roof.

These savings occur from the insulating effects of the solar air space, radiant barrier , and fiberglass insulation in the roof, which keep the existing built up roof below cooler than an exposed, non-solar built up roof.

Analysis of the solar roof relative to a retrofit of a reflective 'cool' roof indicates that the 'cool' roof will provide about the same cooling savings as the solar roof. For Fort Meade, the difference in cooling cost savings would only be +/- $20 per year depending on the estimating technique. However, a solar roof retrofit, instead of a 'cool' roof membrane retrofit, saves $5,487 in roofing and heating savings compared to installing a cool roof just to cut cooling costs.

References

1. Department of Defense Environmental Security Technology Certification Program (ESTCP) is DoD's environmental technology demonstration and validation program. The Program was established in 1995 to promote the transfer of innovative technologies that have successfully established proof of concept to field or production use.
   http://www.serdp.org/About-SERDP-and-ESTCP/About-ESTCP

2. 2001 ASHRAE Handbook, Fundamentals,
   American Society of Heating Refrigeration and Air Conditioning Engineers,, Inc.
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3. Dept. of Energy DOE Cool Roof Calculator
   CoolCalcPeak program
   http://www.ornl.gov/sci/roofs+walls/facts/CoolCalcEnergy.htm

4. Modeling the Thermal Performance of Ballasted Roof Systems Dejarlais, Petrie, Atchley, ORNL, ASHRAE 2007, Building X conference
   www.ornl.gov/sci/roofs+walls/staff/papers/21.pdf

Extended List of Findings and Results:

For many facility managers and design professionals, a snapshot of results and performance of one project is helpful in understanding the scope of the project and approaching the design of a new system. Toward that end, the following is a list of findings and results from the Gaffney Fitness Center Solar Air Heating Re-roof that will help the reader to quickly get a sense of the scope, performance, and economics of the solar air heating re-roof relative to it impact on Heat gain during the summer cooling season.

Results:

The Solar Air Heating Roof:

1. **Reduces the summer cooling load on the building,** by an estimated $83 per year.
2. Reduces peak electricity demand by cutting air conditioning load during the most expensive peak demand hours
3. Provides significant solar water heating capability during the cooling season including spring, summer, and fall
4. Reduces the combined building cooling load and domestic hot water heating load, by about 11 times more than the reduced energy load from the best 'cool roof' alone
5. Provides cooling cost savings that are about 1% of the total roofing, heating, and cooling savings.
6. Provides a very large space heating and outdoor air preheating capability during the fall, winter, and spring heating season
7. Provides a long life, weathertight roof.

Addendum

<u>Cooling Savings from the Solar roof area over the flat roof</u>

The Solar re-roof of the Gaffney Gym involved two types of metal roof retrofit. The primary area with 7,715 square feet of solar roof, involved a retrofit of the metal roof installed a few inches above the existing sloped gym roof. See Figure A-3, 20.

A second area, of 1,560 square feet, involved the installation of a solar metal roof over a low slope roof using a 'slope build-up' system. The 'simplified' sketch below shows a schematic of the primary area to the right and the slope build-up area to the left. The area to the left created a solar mechanical room that was built on top of the existing Built Up Roof (BUR). The old BUR in the mechanical room is installed above 4" of polyiso insulation which sits on the roof deck (R value ~25). A drop ceiling sits 18" below the corrugated deck and forms a return air plenum at the same temperature as the space below, ~70F.

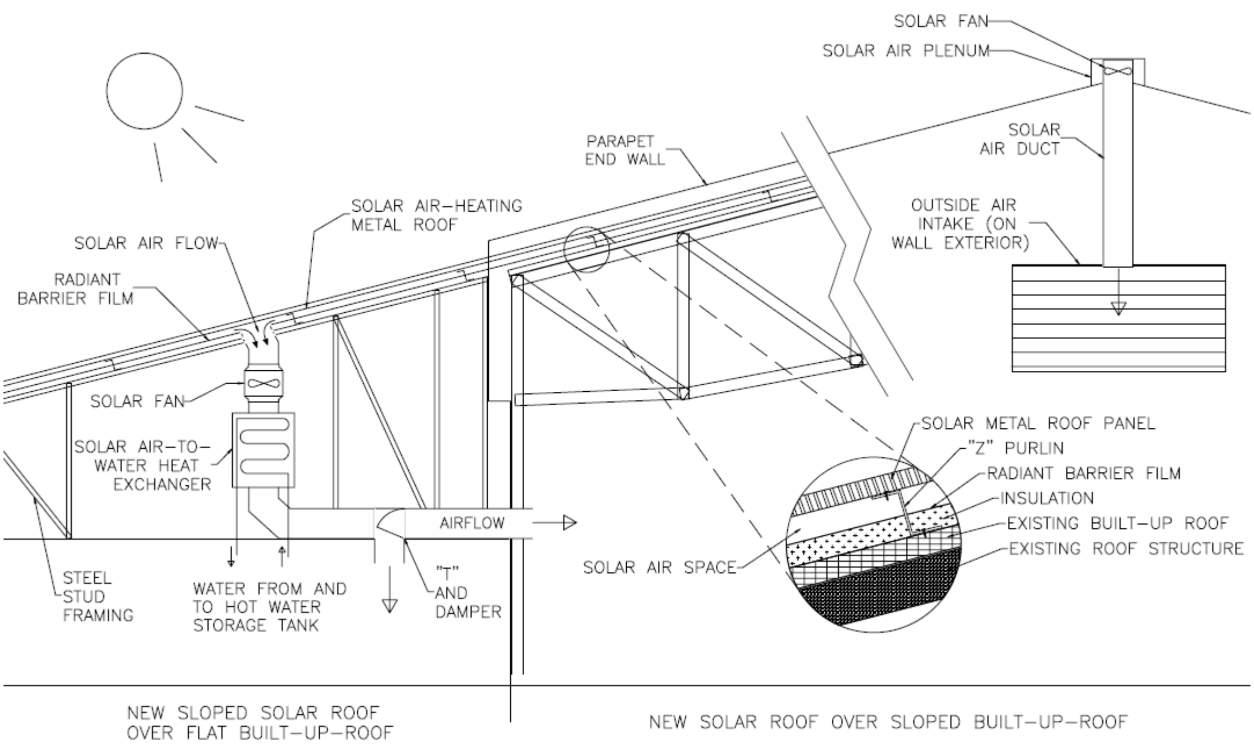

Figure A-3, 20 Concept Schematic Section

The solar metal roof panels are continuous from the gym ridge to the eaves of the solar roof over the mechanical room. Above the mechanical room, the metal roof panels are attached to new purlins that range from 8' to 14' above the old BUR. (See Figure A-3, 21.) Beneath the purlins, a radiant barrier film is attached to cut radiant heat from the bottom of the hot solar roof panels down to the old BUR (See Figure A-3, 22.) On top of the old BUR, a 6" layer of fiberglass insulation is installed in most areas. In a few walkways, the old BUR is exposed. Solar heated air is drawn from the area below the metal roof panels and above the radiant barrier. The 420 cubic feet per minute (cfm) of solar air is blended with 2,931 cfm of solar air from above the gym to feed the air-to-water heat exchanger. Testing has shown that the solar air from each source is at the same temperature, which is recorded as the solar air into the heat exchanger.

Figure A-3, 21 Sloped Build Up Structure

During a test at 13:25 on 7/25/12, temperatures were taken of the

- solar air at the top of the gym solar roof
- solar air into the air-to-water heat exchanger
- air temperature in the mechanical space 8' above the old BUR
- the temperature of the old exposed BUR on a walkway in the mechanical room (IR surface spot) and
- the temperature of the old BUR under 6" of fiberglass insulation (IR surface spot)
- the underside of the metal roof panel just above the eaves in the mechanical room (IR surface spot)
- the surface temperature of the old exposed BUR outside on the low slope roof near the new solar roof area, locations 40, 41 (IR surface spot)
- the temperature under an exposed, loose laid, 6 sqft, new, white BUR at location 40, 41 (portable thermistor sensor and IR surface spot). See Table A-3,9.

Figure A-3, 22 Solar Mechanical Room

Solar air at the top of the gym roof was 142F
Solar air temperature to the heat exchanger was 119F,
Air temperature in the mechanical space was 90F,
Exposed BUR was 77F,
The BUR under the 6" of fiberglass was 72F,
The underside of the roof panel was 136F,
The old BUR at location 40, 41, was 150F,
The loose laid new BUR was 140F.

Table A-3, 9 Mechanical Room Solar & IR Temps

The key temperatures to focus on are the temperature of the old BUR below the fiberglass, and the temperature of the old and new BUR exposed outside the mechanical room.

The covered BUR under the solar roof was 72F while the exposed BUR outside the mechanical room averaged 145F. With a space temperature below the solar roof of ~70F, the temperature difference between the covered solar BUR and space is insignificant, ~2F. The temperature between the exposed BUR outside the mechanical room and the space is ~75F.

With an R value of 25, the heat transfer from the hot exposed BUR to the ceiling plenum below would be 3 BTU/sqft/hr. For the 1,560 square feet of the mechanical room, the heat load from the exposed BUR would have been 4,680 BTU/hr. To remove this heat from the building would require about 0.5KW of electric power for an air conditioner with a COP of 2.5.

<u>Conclusion</u>

The solar roof installed in a slope build up system, with radiant barrier and fiberglass insulation on the old BUR reduces the peak heating load on the old, covered, low slope roof by about 3 BTU/sqft/hr, essentially eliminating any heating load on the old roof.

Appendix A-4: Fire Protection,

Fire Protection Considerations for Solar Air Heating Roofs

Executive Summary:

Background: American Solar, Inc. evaluated its solar air heating roof system on the delivery of solar heated air for space heating, outdoor air preheating, and water preheating. This analysis is part of a larger project to document the overall annual energy and life cycle roofing benefits of a solar air heating roof.

The project is funded by the Department of Defense Environmental Security Technology Certification Program (ESTCP) (Ref. 1). The Solar roofed building is the Gaffney Fitness Center at Fort Meade, MD.

Part of the project was to evaluate the insulation requirements for installation above a Built Up Roof (BUR). A particular focus was a review of the existing fire protection requirements from building codes and recommendation for an insulation layer above a Built Up Roof. This insulation layer drives the structural support type, depth, weight, and cost for the solar roof.

Findings: The following summarizes the findings:

1. The building codes were not written with this type of retrofit construction in mind. The exception is the Factory Mutual guidance which recommends insulation thicknesses based on the type of existing roof.
2. The current approach for most metal roof retrofits is to seek a local approval for the arrangement of the metal roof retrofit from the code Jurisdiction Having Authority. In many cases, no insulation has been required above the old BUR.

Results:

1. The Gaffney roof installation followed the Factory Mutual data sheet and added 6 inches of fiberglass insulation above the existing BUR for fire protection of the old roof.
2. The consensus among fire protection experts is that there is no current approach to design that is universally accepted for a metal roof retrofit and that local approval is required.
3. Elements of the existing building code can be interpreted to require separation of the solar roof air space to a minimum are of 3,000 square feet.

Introduction:

There has been very little published data on the design of solar air heating roofs that use conventional metal roofing above a Built Up Roof and how to integrate the solar re-roof into the building in a code approved way. The design requirement documents that do exist were not developed with a solar air heat recovery system in mind. In most cases the national building codes have not yet been written with a comprehensive review of a metal re-roof over a Built Up Roof with regard to fire protection. For the millions of square feet of metal roof retrofits already in place, it is safe to say that the local jurisdictions have been the only organization performing a review of the designs. The local review adds cost and delay and uncertainty in the design of any solar roof when compared to a national standard for such design.

One document from a national source involved in building design approval is Factory Mutual (FM) Data Sheet 1-31 (Ref. 2). This data sheet discusses varied approaches to the protection of the existing BUR below a retrofit metal roof.

Even with the FM Data Sheet, the selection of fire protection requirements is based on the type of BUR system installed. Unfortunately, in many cases, the type of BUR installed can not be determined. This is caused in part by the application process of the BUR, which covers any marking of the BUR type that is installed by the asphalt that seals the bottom of the cap sheet to the layer below. In addition, when a BUR needs to be re-covered, it is typically 15+ years old and the original records and knowledge of what was installed may no longer be available from the building owner or long departed staff members. In a case where the type of installed BUR is unknown, the decision on what type of insulation should be used to cover the BUR becomes uncertain in the FM data sheet.

Beyond the FM Data Sheet, some design requirements and information can be determined from a reading of various sections of the existing national building codes. These include the following codes and sections:

IBC (Ref. 3) Section 603, 716, 718, 1202.2, 1510, 2603.4, 3409
NFPA 5000 (Ref. 4) Section 3.3.477, 7.2.3.2.15, 8.14.1.1,
NFPA 90A (Ref. 5) Section 4.3.5.3, 4.3.11.2

However, these requirements and information were never written with the particular intent of covering a built up roof and they provide conflicting guidance in different sections. Among these codes, even the description of the space enclosed below the solar metal roof, is not specifically defined. Depending on the interpretation, it may be considered an attic, a plenum, a ventilation space, or a concealed space. Each term brings its own set of requirements and in many cases the requirements conflict.

One example of a requirement is from Section 716.4 of the International Building Code (Ref.3), which requires draft stopping in attic concealed spaces. The requirements limit the maximum area without draft stopping to 3,000 square feet. This requirement has minimal impact on solar air heat recovery.

Other requirements indicate that the construction in concealed spaces should be of non-combustible materials. Fiberglass insulation is normally considered to protect combustible materials and is allowed or required to cover otherwise combustible attic floors if they are only used for access for mechanical room maintenance.

In other parts of the code, a 1.5” thick layers of fiberglass, is permitted to cover combustible plastic insulation in attic spaces. This permission bears some relationship to the fiberglass covering of a BUR in the FM data sheet. However, the fire testing of an approved BUR roof is not equivalent to the fire testing of other building materials such as foam plastic.

In general, the fire testing of a BUR roof surface is designed to evaluate a fire on top of the roof surface and ,separately, below the roof surface, to validate that the roof contributes minimal fuel to a fire. Further, a roof assembly of roof deck, insulation, and BUR are tested to confirm that a fire that occurs above a roof will not advance down to the space below the roof deck. Certainly if there is gravel ballast above the cap sheet, the chances of the BUR burning from above are minimal. With a tested BUR the growth of any flame above the BUR will be limited.

This supports a view that many code approved BURs are relatively incombustible as installed. The testing method for a BUR does not generate a smoke or flame spread value comparable to the values generated for other tested interior combustible building materials such as foam plastic. The addition of fiberglass insulation above the BUR adds an additional layer of fire protection from an ignition source on top of the BUR.

The appropriate amount of fiberglass above the BUR is an important question from the standpoint of structural support, weight, and cost of a metal re-roof. For example, the Gaffney roof used 2 layers of structural ZEE channel to support the metal roof panel at a height of 9.5" above the BUR. See Figures A-4, 1-3. This is driven by the 6" fiberglass layer that necessitates a 6" ZEE running vertically up the slope which is then crossed with a second set of 3.5" ZEEs. The spacing of the 6" Zees depends on the appropriate spanning distance of the 3.5" Zees to handle the roof loads.

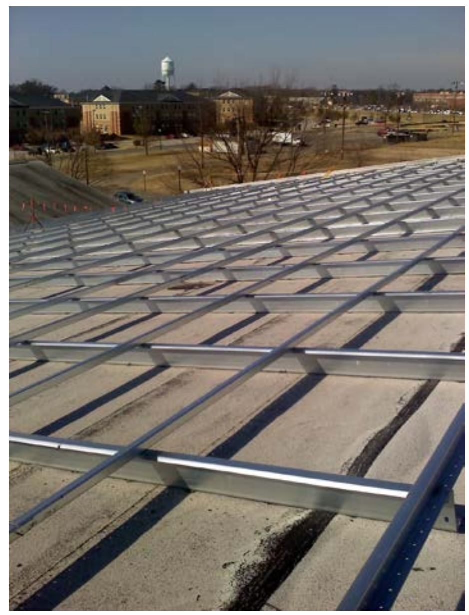

Figure A-4, 1 Solar Roof Support Structure on Gym Roof

If the required thickness of fiberglass were reduced to 1.5" (similar to that required for covering combustible plastic foam) then the 6" Zee could be eliminated and a smaller ZEE or hat channel could be installed directly on the BUR to support the roof panels. Because the smaller Zee would be evenly supported across the BUR, the depth for structural support could be reduced to only that required to support solar air flow above the fiberglass. In such a case, a 2.5" ZEE could be installed.

This reduction of insulation thickness would eliminate several thousand dollars of material and labor from the 'as installed' case at Gaffney. For example, over 3,000 linear feet of 6' Zee are installed at Gaffney. The material costs are over $6,000 and there are increased handling and labor costs required to install the Zees, the fiberglass, and the radiant barrier compared to a single transverse ZEE or hat channel installed directly on the BUR. Overall, the cost savings of installing the single transverse support would be about $3-4 per square foot of solar roof installed. This is enough to lower the cost of a 9,275 square foot solar roof section by about $30,000. For the case where such a roof is operated with maximum energy savings at Gaffney the payback period drops from 12 years to 9 years compared to a series of built up roofs.

Figure A-4, 2 Solar Roof Support Structure on Gym BUR

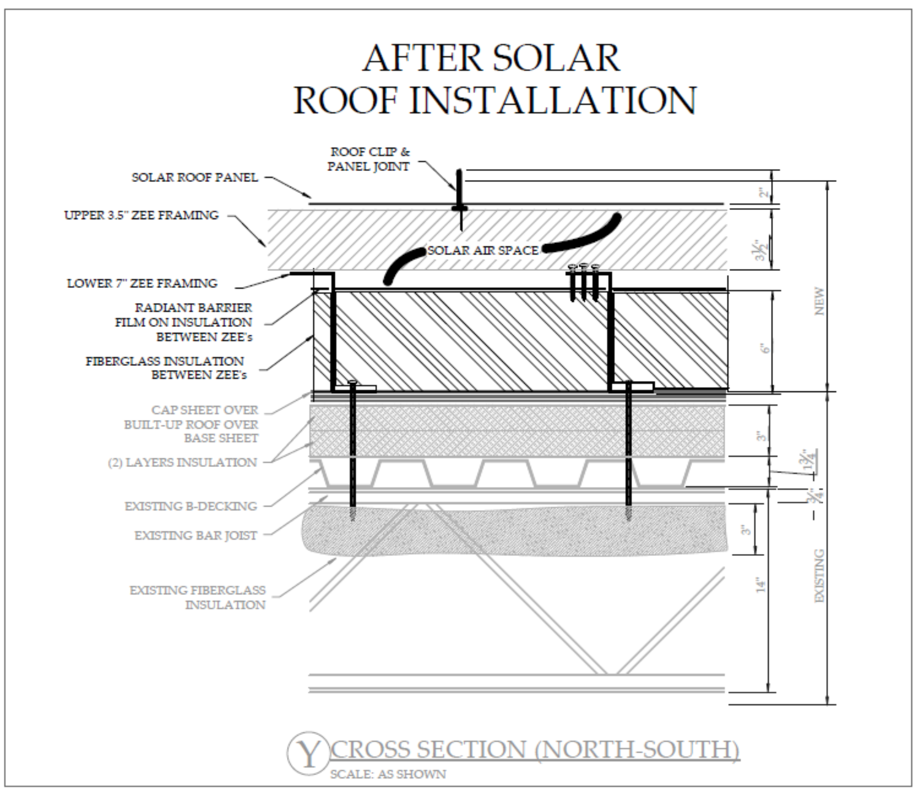

Figure A-4, 3 Roof Section , AS-Built

American Solar consulted with several experts in the field of fire protection to determine if there was a way to gain approval of a standard design for the re-roof over any Built Up Roof system. See references. Options discussed included the use of analytic fire modeling and submittal to Code Evaluation Services for endorsement. All parties agreed that given the variability of the BURs and the unknown characteristics of each roof, that there is currently no process to approve a standard design.

As a result, in the future, American Solar will proceed with a local approval of the design, using the codes mentioned in this paper.

Summary

The solar roof retrofit on the Gaffney Fitness facility complies with the best available design guidance for a metal retrofit over a built up roof.

There is currently no method of approving a standard design for such a system and all approval must be by the local jurisdiction having authority.

References

1. Department of Defense Environmental Security Technology Certification Program (ESTCP) is DoD's environmental technology demonstration and validation program. The Program was established in 1995 to promote the transfer of innovative technologies that have successfully established proof of concept to field or production use.
   http://www.serdp.org/About-SERDP-and-ESTCP/About-ESTCP
2. Factory Mutual Data Sheet FM 1-31
3. International Code Council, Falls Church, VA, International Building Code, Section 603, 716, 718, 1202.2, 1510, 2603.4, 3409
4. National Fire Protection Association, Quincy, MA, NFPA:5000, Building Construction and Safety Code, Section 3.3.477, 7.2.3.2.15, 8.14.1.1
5. National Fire Protection Association, Quincy, MA, NFPA 90A: Standard for the Installation of Air-Conditioning and Ventilating Systems, Section 4.3.5.3, 4.3.11.2
6. Meeting with W Koffel, T Cates, Koffel Associates, July, 8, 2011
7. Telephone Conversation with Anthony Hamins, Chief Fire Research Division, National Institutes of Standards and technology, July, 19, 2012
8. Telephone Conversation with Bohdan Horeczko, P.E., Director, Professional Services, ICC Evaluation Service, LLC August 26, 2011
9. Telephone Conversation with Jim Milke, Chair, Dept. of Fire Protection Engineering, Univ. of MD, September 13, 2012
10. Telephone Conversation with Mark James, Roofhugger, August 2011

Appendix A-5: Life Cycle Cost,

Note: This Appendix, A-5, presents the results of a life cycle cost analysis using discounted cash flows for the roof and energy costs. The discount factors are taken from the NIST and OMB factors available from the Federal Energy Management Program. However, this analysis was not conducted using the BLCC program. The results of a BLCC analysis are included in Appendix B of the final report. In general, the BLCC analysis identifies a higher annual and life cycle savings potential for a solar re-roof than the analysis below, which used more conservative roof and energy savings values.

Solar Air Heating Roofs: Life Cycle Cost

<u>Executive Summary:</u>

Background: American Solar, Inc. evaluated the capability of its solar air heating roof system to deliver solar heat for a variety of uses. This analysis is part of a larger project to document the overall annual energy and life cycle roofing benefits of a solar air heating roof.

The project is funded by the Department of Defense Environmental Security Technology Certification Program (ESTCP) (Ref. 1). The Solar roofed building is the Gaffney Fitness Center at Fort Meade, MD.

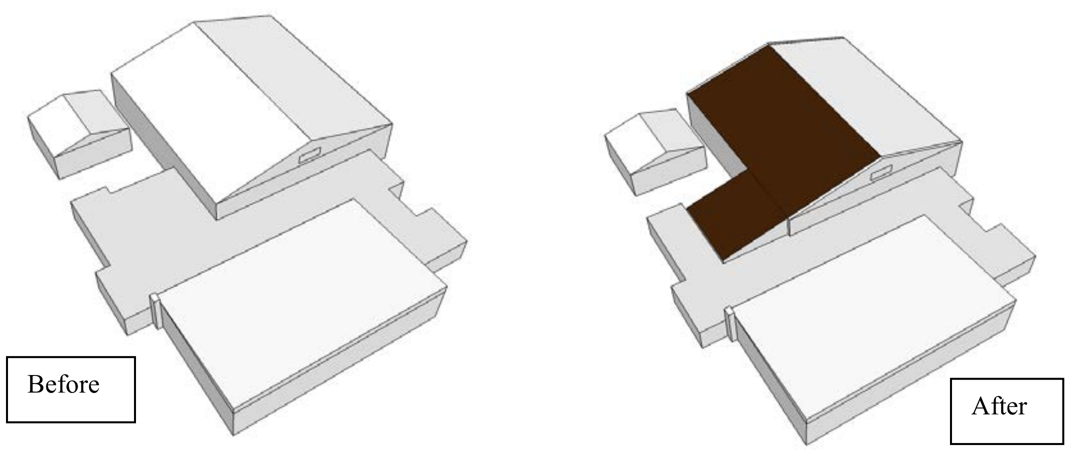

Figure A-5, 1 Before and After

The installation included 9,275 square feet of solar air heating roof installed as one continuous sloped roof. A 7,715 square foot section of the roof was installed above an existing sloped Built Up Roof (BUR) and a 1,560 square foot section was installed over a lower section of flat built up roof, creating a new mechanical room. See Figure A-5, 1. This permitted temperature testing of solar roof with both an enclosed solar air space above the sloped (BUR) and a semi-enclosed solar air space at the top of the mechanical room.

The following summarizes the analysis with a focus on the life cycle cost of a solar air heating re-roof.

Results:

1. The installed solar re-roof of the Gaffney Fitness Facility can provide maximum natural gas cost savings of $4,250 per year.
2. The net present value cost of the Gaffney Fitness Facility solar re-roof system, as installed, is a savings of $1,678 per year, including solar re-roof costs, avoided Built Up Roof costs, and maximum energy savings.
3. Continuing with the existing, non-solar BUR, would have a net present value cost over 30 years of $244,424 and would provide no energy savings.
4. The solar re-roof, as installed, over both the sloped and flat BUR sections cost $37/sqft ($20/sqft over sloped BUR and $74/sqft over flat BUR).

Introduction:

The solar air heating roof retrofit on the Gaffney Fitness Center involved the installation of a black metal standing seam roof over a metal substructure with fiberglass and radiant barrier insulation. This retrofit was installed directly over the existing sloped built up roof (BUR) which was on top of a polyisocyanurate (Polyiso) board insulation and corrugated metal deck. Inside the building, at the ceiling of the gym, a 3" thick fiberglass insulation with cloth jacket covered the bottom of the metal deck.

Figure A-5, 2 Gaffney Aerial View

The section over the flat Built Up Roof was installed on supporting structure tied to the building structure below the roof.

The aerial photos, Figures A-5, 2&3, show the before and after shots of the solar roof.

The schematic below, Figure A-5, 4, shows the system as proposed at the start of the project. Following award of the ESTCP contract, the Corps of Engineers commenced a separately planned and funded HVAC upgrade to the gym which relocated the outside air intake on the southeast exterior wall. The new location of the outside air intake is on an air handler on the ground, to the southwest of the gym. As a result, American Solar adjusted its design to install the solar air plenum within the new solar mechanical room and to run insulated ductwork down to the air handler on the ground.

Figure A-5, 3 Aerial View AS-Built

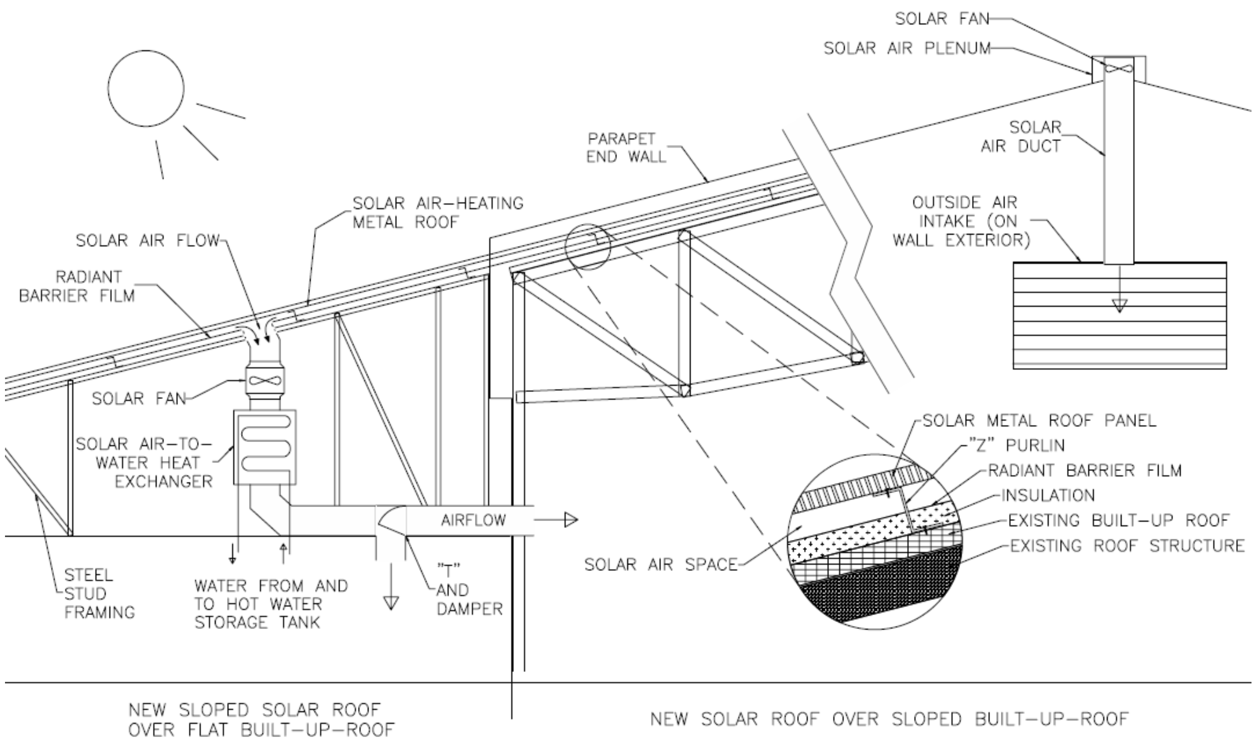

Figure A-5, 4 Concept Schematic Section

The Solar Re-roof provides cost savings in two different ways:

1. Roofing Cost Savings
2. Energy Cost Savings

The roofing cost savings result from the long life of the solar air heating metal roof compared to multiple conventional Built Up Roofs that would be required to match the 40 year life of the metal roof. The arrangement of the solar roof at the Gaffney Fitness Center includes 2 distinct portions, shown above. The portion over the sloped BUR of the gym is installed to the sloped roof, with minimal structural depth added to support the metal roof. The portion of the solar roof added over the flat roof required additional structure and siding, creating a 1,560 square foot mechanical room below the metal roof. This portion of the roof is referred to as the "Slope Build Up" section. The cost for this portion of the roof was considerably more expensive that the portion over the sloped gym roof.

The energy cost savings occur in 5 different ways:

1. Outside Air Preheat
2. Direct Space Heat
3. Summer Roof Cooling
4. Domestic Water Preheating
5. Winter Roof Heating

These different heating and cooling energy savings contribute at different times throughout the year as the solar roof temperatures and the building's energy demand varies. For the summer roof cooling there is only an electrical energy savings from the air conditioning systems. For winter roof heating, there is only a natural gas heating savings from reduced heating boiler gas consumption. For Outside Air Preheat, Domestic Water Preheat, and Direct Space Heat, there is a savings in natural gas heating and a cost for electric energy to run the fans and pump.

During the testing period, the OA preheat, Direct Space Heat and Domestic Water preheat systems were operated on set thermostatic controls. These controls turned the system ON and OFF based on set differential temperatures between the Solar roof air temperature and the temperature of the outside air or domestic water. The value of the ON-OFF differential temperatures, measured every 15 minutes during the testing, were used to calculate the solar heat transferred from the solar heating system to the outside air, domestic hot water, or directly to the gym air. Throughout this paper, we refer to this as the ‘as installed” or "as built" system. This refers to both the physical configuration and the setting of the differential temperature controllers for operations during the testing period.

Subsequent to the testing period, the data collected was analyzed to establish an analytical performance model of the solar re-roof. This performance model evaluated not only the physical energy (BTUs, kwhr) delivered and consumed, but also the economics of the energy cost and savings using local utility rates. The resulting analysis provides an annual energy and cost savings model for the solar air heating re-roof.

This model of the solar re-roof performance is the first of its kind to be documented with a system that actively manages the flow of solar heated air within a roof. It permits the prediction of solar air heating roof performance for any location based on typical meteorological year and solar data. When combined with local heating and electrical energy costs, the model can determine energy cost savings. This includes the maximum physical energy savings and energy cost savings that would be expected given the ideal adjustment of the differential temperature controllers to turn the fans and pumps ON and OFF. In this paper we refer to the operation of the system with the best temperature differential settings as the “maximum energy savings” case. This maximum energy savings case also accounts for increased energy delivery to the water preheat systems when using only cold water supplied to the heat exchanger instead of recirculated preheated water.

The calculation of the roof and energy cost savings used the local utility rates from rates published in a recent energy procurement by Fort Meade. The rates were $8.70 per million BTU for natural gas and $0.115 per kilowatt hour. The condensing natural gas boiler shows an efficiency of 90% when operating at the hot water loop temperature of 130F. So, the delivered cost of natural gas heat to the hot water loops for domestic water heating or building heating is $9.70 per million BTU. All roof and energy savings were discounted using the most recent discounting rates from the NIST BLCC price indices and OMB discount factors (Ref. 2). The analysis was conducted outside of the BLCC program which is separately reported in Appendix B of the Final Report.

Roofing Cost and Savings

The solar air heating roof is a weathertight roof that lasts for 40 years. It eliminates the need for 2+ re-roofings by a built up roof. To compare the two roofing systems we use a 30 year life cycle analysis. This matches the length of 2 BUR re-roofs and matches the maximum years for which there are discount factors available from NIST. Because the solar roof still has 10 years of useful life at the end of the 30 year period, a salvage value is assigned to the solar roof at year 30. This salvage value is 25% of the cost (10years/40 years) times the discount rate at year 30 (.552). Table A-5, 1 shows unit costs for the roof.

Solar Air Heating Roof Cost Allocation				Solar Roof	Solar Roof			
		subtotals	per sq ft costs	zone 1-4 over sloped BUR	zone 5 over sloped build up at Mech. room	Plumbing	Ducts & fans	Roof &Trim
Solar roof cost	$241,295			$140,000	$ 101,295			
Total Roof		$241,295	$ 26					
Electrical	$ 9,421				$ 1,884	$ 1,884	$ 5,653	
Gen'l Construction	$ 16,939					$ 3,388	$ 11,857	$ 1,694
Plumbing	$ 12,848					$ 12,848		
Structural Eng'r	$ 8,880			$ 4,440	$ 4,440			
total subs		$ 48,088	$ 5					
Fans	$5,337						$ 5,337	
Heat Exchanger	$ 1,304					$ 1,304		
Insulation 1	$ 3,664			$ 3,664				
Insulation 2	$ 1,100			$ 847	$ 253			
Ducts 1	$ 6,000						$ 6,000	
Ducts 2	$ 500						$ 500	
Misc.	$ 4,500					$ 900	$ 2,700	$ 900
total materials		$ 22,405	$ 2					
Gen'l Contractor	$ 35,000			$ 7,000	$ 7,000	$ 7,000	$ 7,000	$ 7,000
total GC		$ 35,000	$ 4					
Total all	$346,788			$155,951	$ 114,872	$ 27,324	$ 39,047	$ 9,594
Ave $/sqft			$ 37	$ 20	$ 74	$ 3	$ 4	$ 1

Table A-5, 1Solar Air Heating Roof Cost Allocation

Notes:
Insulation 1 is Solar roof insulation, Insulation 2 is Mechanical system insulation
Ducts 1 is spiral duct, Duct 2 is duct dampers

The solar roof cost for zone 1-4 is the cost of the section of the roof that is over the existing sloped built up roof over the gym.

The solar roof cost for section 5 of the roof is the cost of the section of the roof above the flat built up roof that encloses the new mechanical room. It includes significant new “slope build up” structural support with head room from 8-13 feet above the flat built up roof and 1,403 square feet of new wall surface, shown in Figure A-5, 5.

Figure A-5, 5 Sloped Build Up Structure

Table A-5, 2 below shows the 30 year life cycle cost of a Non-Solar Built Up Roof. It includes present day costs for each of the major roofing expenses. The 30 year value is used for later comparison to the solar roof. A 40 year value is also shown because, at year 30, the BUR would need to be replaced again, while the solar roof still has 10 years of life remaining.

Life Cycle Cost Metrics		Roofing Only	Non-Discounted		Discounted
Non solar roof cost	year	Expense	$/sqft	OMB discount rate	Discounted value
	1	Tear off & dispose & protect	$ 6.00	0.995	$ 5.97
	1	BUR 17 year life	$ 9.00	0.995	$ 8.96
	10	Repair yr 13	$ 2.00	0.82	$ 1.64
	17	Recover yr 17	$ 12.00	0.714	$ 8.57
	25	Repair yr 25	$ 2.00	0.61	$ 1.22
	30	Tear off & dispose	$ 6.00	0.552	$ 3.31
	30	BUR	$ 9.00	0.552	$ 4.97
	40	Repair	$ 2.00		
40 years	40	End of cost comparison			
		Total thru 40 years	$ 48.00		$ 34.63
		Salvage value beyond yr 40	$ (3.71)		$ (2.05)
		Net Cost at Yr 40	$ 44.29		$ 32.59
30 years	30	End of cost comparison			
		Total thru 30 years	$ 31.00		$ 26.35
		Salvage value beyond yr 30	$ -		$ -
		Net Cost at Yr 30	$ 31.00		$ 26.35
Gaffney Cost over 40 year			$ 410,828		$ 302,247
Gaffney Cost over 30 year			$ 287,525		$ 244,424

Table A-5, 2 Non-Solar Roof Life Cycle Cost

A similar table, A-5, 3is shown below for the <u>as installed</u> solar roof. This table includes values for savings and costs for the solar roof – the non-solar roof.

AS INSTALLED		Roofing Only	Non-Discounted		Discounted
Solar metal roof	year	Expense	$/sqft	OMB discount rate	Discounted value
	1	Install over BUR 40 year life	$ 37.39	0.995	$ 37.20
	25	Touchup paint& seal fan replacement	$ 2.00	0.61	$ 1.22
	30	Repaint/recoat	$ 2.50	0.552	$ 1.38
	40	End of cost comparison			
		Total thru 40 years	$ 41.89		$ 39.80
		Salvage value beyond yr 40	$ -		$ -
		Net Cost at Yr 40	$ 41.89		$ 39.80
		Total thru 30 years	$ 41.89		$ 39.80
		Salvage value beyond yr 30	$ (9.35)		$ (5.16)
		Net Cost at Yr 30	$ 32.54		$ 34.64
Net 40 yr (cost) savings per sqft vs. Non-solar			$ (2)		$ (7)
Net 40 yr (cost) savings per sqft per year vs. Non Solar			$ 0		$ (0)
Net 40 yr (cost) savings per year, Gaffney 9275 sqft			$ (558)		$ (1,673)
Gaffney Cost over 40 year			$ 388,526		$ 369,169
Gaffney Cost over 30 year			$ 301,829		$ 321,312
40 year Net (cost) savings, Gaffney 9275 sqft			$ 22,302		$ (66,921)
30 year Net (cost) savings, Gaffney 9275 sqft			$ (14,304)		$ (76,888)

Table A-5, 3 Solar Roofing, Life Cycle Cost

As installed, with the addition of the expensive 'sloped build up" section over the mechanical room, the Gaffney roof is $76,888 more expensive as a roof than 30 years of BUR.

One additional table is shown below that compares the solar roof of comparable area (9,275 square feet) constructed just over a sloped BUR, costing $20/sqft, similar to the cost of the section of the Gaffney roof over the sloped BUR. This roof is considerably less expensive and is lower life cycle cost than the BUR or the As installed roofs.

Solar over sloped BUR	Using unit cost of solar roof over sloped BUR		Non-Discounted	OMB discount rate	Discounted
	year	Expense	$/sqft		Discounted value
Solar metal roof	1	Install over BUR 40 year life	$ 20.00	0.995	$ 19.90
	25	Touchup paint& seal fan replacement	$ 2.00	0.61	$ 1.22
	30	Repaint/recoat	$ 2.50	0.552	$ 1.38
	40	End of cost comparison			
		Total thru 40 years	$ 24.50		$ 22.50
		Salvage value beyond yr 40	$ -		$ -
		Net Cost at Yr 40	$ 24.50		$ 22.50
		Total thru 30 years	$ 24.50		$ 22.50
		Salvage value beyond yr 30	$ (5.00)		$ (2.76)
		Net Cost at Yr 30	$ 19.50		$ 19.74
Net 40 yr savings/sqft vs. Non-solar			$ 19.79		$ 10.09
Net 40 yr savings/sqft/yr vs Non Solar			$ 0.49		$ 0.34
Net 40 yr savings/sqft/yr, Gaffney 9275 sqft			4,590		3,119
Gaffney Cost over 40 year			$227,238		$ 208,688
Gaffney Cost over 30 year			$227,238		$ 183,089
40 year Net cost savings, Gaffney 9275 sqft			$183,590		$ 93,560
30 year Net cost savings, Gaffney 9275 sqft			$106,663		$ 61,336

Table A-5, 4 Solar Roof Unit Cost & Savings

Over 30 years, a solar roof, installed over an existing sloped roof would save $61,336 compared to a series of Built up roof repairs and replacements.

Energy Cost and Savings

During the testing period, the solar roof was operated to maximize the production of heating energy savings for domestic water preheating and outdoor air preheating. Electrical energy consumption for the fans and pump were measured to support development of the energy metrics but were a secondary consideration during the testing period.

This approach permitted the heating performance to be determined, for all hours that the system could provide heat, even when the electrical energy costs might have been higher than the natural gas savings. This permitted the regression analyses to develop the accurate predictive model for the solar heating system, regardless of the electrical energy use.

Once the model was developed, it could be used to establish the optimum TURN ON-OFF temperatures that would ensure that the system always delivered net positive cost savings when operating. The model is also valuable for predicting TURN ON-OFF temperatures when solar roofs are installed under different electric and gas/oil heating rates.

Using the recently published rates of $0.115/kwhr and $8.70/million BTU Table A-5, 5 shows the as installed energy savings for the 5 different elements of annual energy savings.

Electricity		Kwhr/yr	$/yr
	OA preheat electricity	2,051	$236
	Direct Space heat Electricity	1,506	$173
	Summer Roof Heat Gain electricity	(583)	-$67
	Water Preheat Electricity	4,952	$569
	total/yr	7,926	$912
Gas		Million BTU/yr	
	OA preheat gas	119	$1,060
	Direct Space heat gas	45	$404
	Winter Heat Loss gas	23	$206
	Water Preheat gas	58	$572
	total /yr	245	$2,241
	net (gas-electricity)/yr		$1,679

Table A-5, 5 Solar Roof Savings by End Use, As installed

Total net cost savings for the as installed case as it was operated during the testing period is $1,679/ year.

Table A-5 ,6 shows the energy cost and savings for the Maximum Energy Case. This case shows the additional energy savings that can be achieved when the differential temperature controls are adjusted to maximize energy production during just those hours where there is net positive cost savings ($ gas-$elec.>0). This case also accounts for the maximum energy delivery from the water preheat system operating with constant cold water inlet temperature instead of the higher temperature recirculated, preheated water.

Electricity		kwhr	$/yr
	OA preheat electricity	2,738	$315
	Direct Space heat Electricity	1,506	$173
	Summer Roof Heat Gain electricity	(583)	-$67
	Water Preheat Electricity	4,952	$569
	total/yr	8,613	$991
Gas		Million BTU/yr	
	OA preheat gas	179	$1,652
	Direct Space heat gas	45	$404
	Winter Heat Loss Gas	23	$206
	Water Preheat Gas	213	$2,107
	total /yr	460	$4,370
		net (gas-electricity)/yr	$3,379

Table A-5, 6 Solar Roof Savings by End Use, Max Savings

This maximum savings case provides net energy savings of $3,379 per year.

Combined Roof and Energy Savings

A 30 year discounted cash flow for the individual and combined roof and energy savings was compiled. The 4 cases compiled for equal roof areas of 9,275 sqft were:

1. As Installed and operated during the testing period
2. As Installed with Maximum Energy Savings
3. Installed over Sloped BUR and as operated during testing
4. Installed over Sloped BUR with maximum energy savings.

Figure A-5, 6 shows the 4 cases plotted over 30 years, including the salvage value of the solar roof applied in the last year.

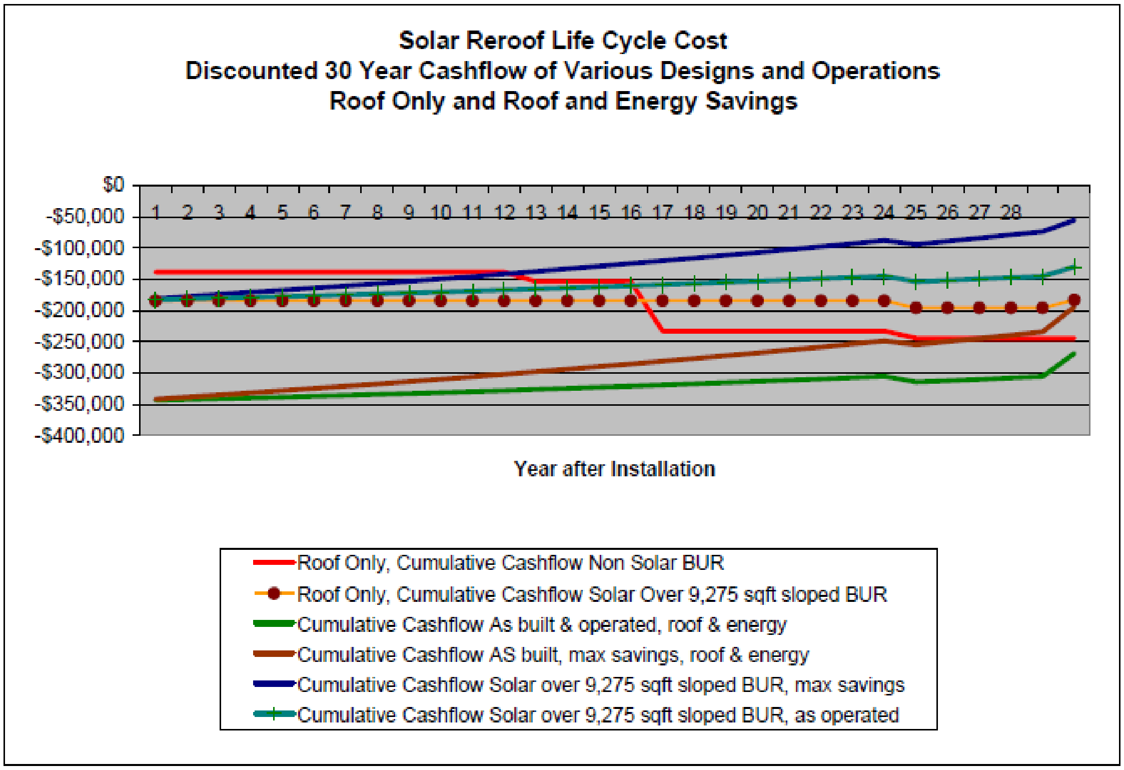

Figure A-5, 6 30 Year Life Cycle Cost, Roof & Energy

The chart shows that the solar roof as installed and operated during the testing period has a net present value of $24,112 less than 30 years of non-solar BURs. However, if the same roof were operated with differential temperature controllers set to maximize net energy savings and a supply of cold water to the heat exchanger, the systems would provide a net savings of $50,363.

The chart also shows that if the solar roof is only installed over the sloped built up roof, and operated as it was during the testing period, the system saves $114,223 over the 30 year life. If the systems is installed over a sloped BUR and operated for maximum energy savings, it saves $188,689 compared to 30 years of non-solar BURs. In this case, the installed cost is $185,500 and the 30 year discounted cost of the solar roof is $183,089 (including the salvage value). So, in this case, the solar roof operated at maximum energy savings provides enough cost savings ($188,689) compared to the non-solar BUR to pay for the next solar re-roof ($185,500).

Figures A-5, 7&8 show the discounted cash flows for the roof cost and for the energy savings for the various non-solar and solar roof options.

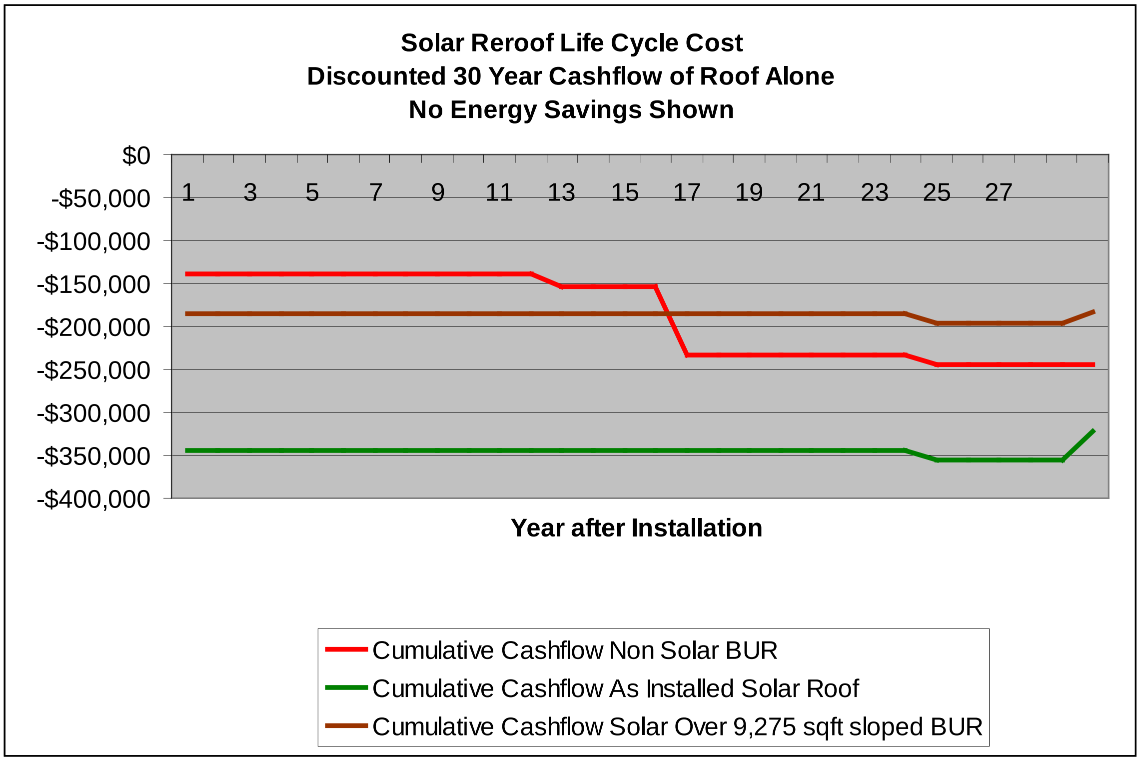

Figure A-5, 7 30 Year Life Cycle Cost, Roofing Only

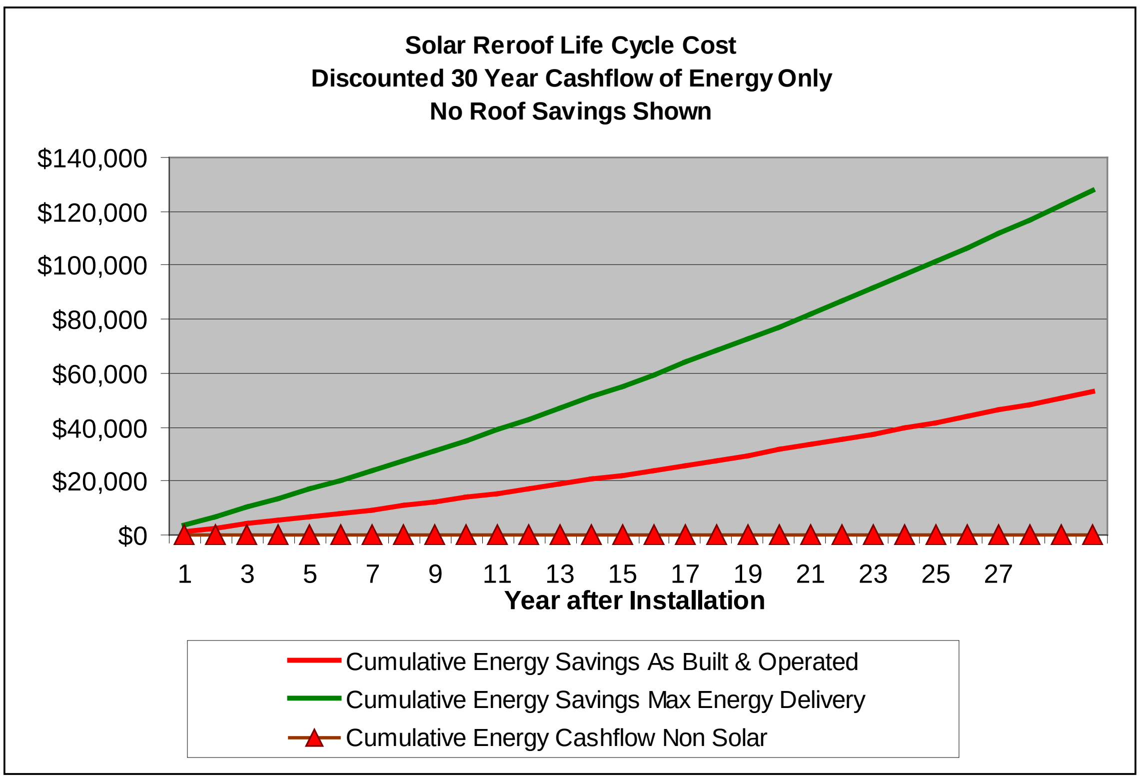

Figure A-5, 8 30 Year Life Cycle Cost, Energy Savings Only

References

1. Department of Defense Environmental Security Technology Certification Program (ESTCP) is DoD's environmental technology demonstration and validation program. The Program was established in 1995 to promote the transfer of innovative technologies that have successfully established proof of concept to field or production use.
   http://www.serdp.org/About-SERDP-and-ESTCP/About-ESTCP

2. Amy S. Rushing, Joshua D. Kneifel, Barbara C. Lippiatt
   Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2012
   Annual Supplement to NIST Handbook 135 and NBS Special Publication 709
   Report # NISTIR 85-3273-27
   http://dx.doi.org/10.6028/NIST.IR.85-3273-27

Results:

1. The installed solar re-roof of the Gaffney Fitness Facility can provide maximum natural gas cost savings of $4,250 per year, or $127,491 over 30 years.
2. The net present value cost of the Gaffney Fitness Facility solar re-roof system, as installed, is a savings of $1,678 per year, $50,363 over 30 years. This combines:1) solar re-roof costs, 2) avoided Built Up Roof (BUR) costs, and 3) maximum energy savings for the installed system,
3. Continuing with the existing, non-solar BUR, maintained, and replaced over 30 years would cost $139,125 to install and have a net present value cost over 30 years of $244,424, or $26.35/sqft. There would be no energy savings from the non-solar BUR.
4. The solar re-roof, as installed, over both the sloped and flat BUR sections cost $37/square foot and has a net present value cost over 30 years of $321,552, or $34.67/sqft (including 10 years of salvage value for the 40 year roof).
5. The solar re-roof, as installed over the sloped BUR costs $20/square foot to install.
6. The solar re-roof, as installed over the flat BUR, costs $74 per square foot of roof and created a new 1,500 square foot enclosed mechanical room with an average roof height of 10 feet.
7. A solar re-roof over just a sloped BUR, with comparable area (9,275 sqft) would have an installed cost of $185,500 and a present value cost over 30 years of $183,216. (Including 10 year salvage value for the 40 year roof). This is $61,208 less expensive than 30 year cost of the non-solar BUR.
8. A solar re-roof over just a sloped BUR, would have a present value cost over 30 years of $19.75 per square foot. (Including 10 year salvage value for the 40 year roof). This is $6.60 less per square foot than 30 years of BUR.

Appendix A-6: Radiant Barrier

Solar air heat recovery from an existing metal roof retrofit with radiant barrier insulation for geothermal heating

<u>**Executive Summary:**</u>

Background: American Solar, Inc. designed and evaluated the installation of radiant barrier insulation under a retrofit metal re-roof to support solar air heat recovery from the metal roof. The impact of the radiant barrier on the attic temperatures and the potential for solar heat recovery from the air above the radiant barrier were evaluated. The radiant barrier had a positive impact on reducing heat transmission from the bottom of the metal roof panels to the surface of the old roof below. This analysis is part of a larger project to document the overall annual energy and life cycle savings from developing a solar assisted geothermal heating and cooling system.

The project is funded by the Department of Defense Environmental Security Technology Certification Program (ESTCP) (Ref. 1). The solar roofed building is Building 601 of the US Marine Corps Air Station (MCAS), Beaufort, SC. This work was conducted under a subcontract to Clemson University, which was under contract to the ESTCP program to validate a low cost method of transferring heat to and from two geothermal fields at the building.

The following summarizes the analysis:

1. The solar air temperature in the attic space below the retrofit metal roof is sufficient to support solar heat recovery for a geothermal loop and other uses within the building.
2. The installation of a radiant barrier film insulation below the retrofit roof reduces the radiant heat transmission from the bottom of the hot metal roof panels down to the surface of the old roof below.
3. The radiant barrier film helps to stratify the solar heated air below the metal roof panels ensuring high temperature air for the attic exhaust fan inlets.
4. The existing metal roof retrofit and attic exhaust fans have sufficient capacity to provide significant annual solar heat for a variety of purposes within the building.

In January 2012, American Solar conducted a site visit to assess the capability of the building to support a solar heat recovery system using the existing metal roof retrofit. The site visit was followed by an engineering design of the solar heat recovery system using the existing roof and attic exhaust fans and ducts, with new heat exchangers, piping, controls, and a radiant barrier insulation system. In April 2012 the radiant barrier film was installed and a set of temperature measurements were made to validate the solar air temperatures that would be available to drive the air to liquid heat transfer to the geothermal loop. The measurements proved the solar heated air resource and attic exhaust fan system are adequate for solar heat recovery to support a geothermal heating system.

Subsequent to the radiant barrier installation the overall geothermal project was reconfigured due to budget constraints related to the installation of a new ground loop for the geothermal system.

Results:

The Solar Heat Recovery System based on the retrofit roof and attic exhaust fans:

1. Can provide sufficient heating for a geothermal heating loop.
2. The radiant barrier film installation reduces the heating load on the old roof (attic floor), keeping attic floor temperatures close to outdoor air temperatures during sunny days.
3. The radiant barrier film insulation helps to stratify the air between the hot air above the barrier and the cooler air below the barrier, with a peak 40 degree F temperature difference across the barrier being recorded.
4. The radiant barrier film insulation helps to create a warm air channel to the attic exhaust duct inlets to prevent mixing with the cooler air below and support the exhaust of the highest temperature air from the attic.
5. The existing exhaust ducts have the capacity to support an air to liquid heat exchanger
6. Each of the 3 existing fans is moving about 10,000 cfm of attic air and would be acceptable to leave in place with a solar heat recovery system installed, with about 8,000 cfm capacity after inserting the air to liquid heat exchanger.
7. An annual estimate of solar air temperature indicates a peak high temperature of about 127 degrees F, and average temperature of 104F, and approximately 2,500 hours of operation per year,
8. Total energy delivery to the hot ground loop would be about 300 million BTU per year using all 3 attic exhaust systems for solar heat recovery.

Introduction:

The Headquarters Building, 601, at the US Marine Corps Air Station, Beaufort, SC was built in 1958. In 2004 it was renovated. Among the features of the renovation were a geothermal heating and cooling system and a retrofit of a metal roof over the existing built up asphalt roof. See Figures A-6, 1&2.

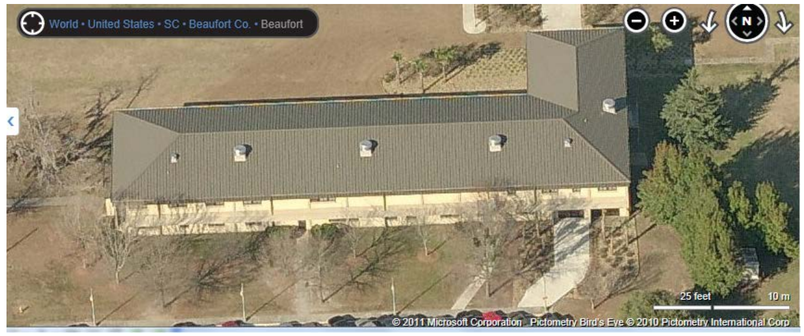

Figure A-6, 1 Metal Re-roofed Building, MCAS Beaufort

In response to a request for proposals from the DOD ESTCP program (Ref. 1), Clemson University proposed that the geothermal system be reconfigured to incorporate a separate hot field and a cold field. Each of these fields would be "charged" with hot or cold geothermal fluids using low cost, low energy heating and cooling systems. The cooling source would be cold air moved across a dry cooler that would use outside air to cool the field in winter. The original solar heating system proposed for charging the hot geothermal field was a set of solar water heating panels mounted on the roof.

Figure A-6, 2 Slope Build Up Metal Re-roof Over BUR

After an initial review the solar heating configuration and the building roof systems, American Solar proposed that a solar heat recovery system (SHRS) be installed to recover heated air from the existing metal roof and supply that heat to the hot geothermal loop. Clemson agreed to proceed and an initial inspection was done on 1/27/12 to verify the configuration of the roof and geothermal system would be compatible with solar air heat recovery. This was followed by a preliminary evaluation of the potential heating capacity of the solar heat recovery system using the existing solar heated attic air and attic exhaust ducts and fans.

Part of the preliminary design indicated that a radiant barrier film insulation should be installed in the attic to help:

- block the heat being radiated from the bottom of the exposed metal roof panels down to the top of the old roof (attic floor),
- reflect radiant heat back up to the bottom of the roof panels to assist in heating the panels and the air in contact with the panels to a higher temperature,
- stratify the solar heated air being generated from the roof panels into an area at the top of the attic space, and

- create a hot air channel above the radiant barrier to support movement of the solar air with minimal mixing with the cooler air below the radiant barrier.

The initial design of the solar roof proceeded using lessons learned from a similar solar air heating roof system being installed by American Solar at the Gaffney Fitness Center at Fort Meade, MD under a separate ESTCP project. Like the Gaffney project, the solar heated air would be drawn from beneath the solar roof panels and pulled across an air-to-liquid heat exchanger. The solar heated liquid would be circulated to the geothermal mechanical room where it would be pumped to the hot geothermal ground loop.

By April it had been decided that the fluid pumped through the heat exchangers in the attic should be a glycol water mixture to provide freeze protection of the coils during cold winter temperatures. A second heat exchanger would be installed in the geothermal mechanical room to transfer heat from the glycol to the water in the geothermal loop.

A schematic of the arrangement of the systems is shown below in Figure A-6, 3 (and Figure A-6, 8 at the end of this appendix.)

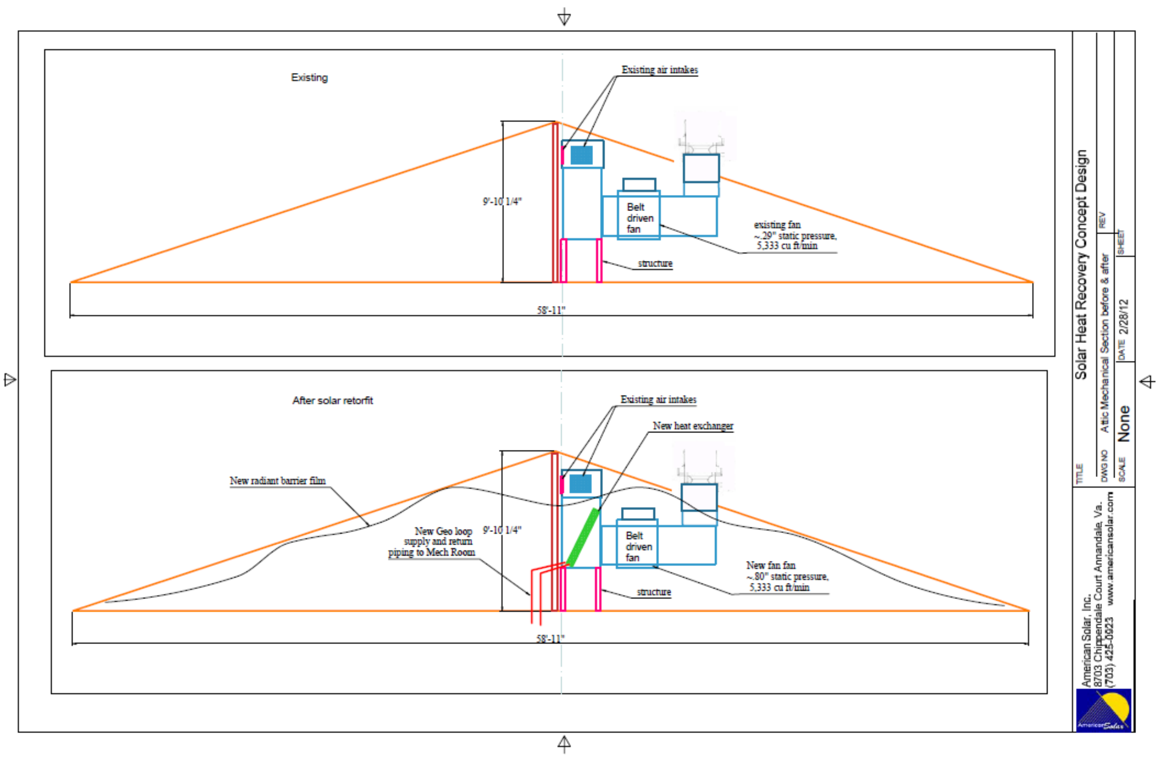

Figure A-6, 3 Solar Heat Recovery Concept

The initial installation began on April 12, 2012 with the installation of the radiant barrier film insulation. During 2 days, 11,000 square feet of radiant barrier insulation was installed in the attic space, below the supporting frame of the retrofit roof. The intent was not to form an air tight space, but simply to block most of the lines of sight from the bottom of the metal roof to the old roof below. Photos of the installed radiant barrier are shown in Figures A-6, 4&5.

Figure A-6, 4 Radiant Barrier Installed

Figure A-6, 5 Radiant Barrier Toward Eaves

During the installation period, the outdoor weather was sunny with cold mornings and warm afternoons. Local weather stations showed nighttime lows of 50F and a daytime high of 70F, with clear sky and winds from 3-10 miles per hour. See Figure A-6, 7.

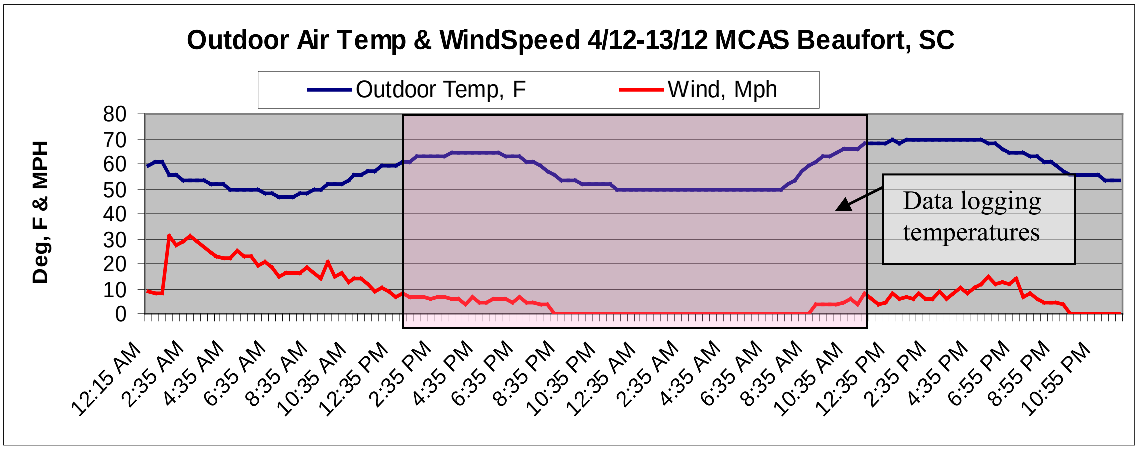

Figure A-6, 6 Weather During Testing Period

The attic was also instrumented with temperature sensors connected to data loggers to record temperatures:

- above the radiant barrier,
- on the attic floor
- at the air inlet to the exhaust fan, and
- at the soffit air inlet to the attic.

The temperatures are shown in the following chart, See Figure A-6, 7.

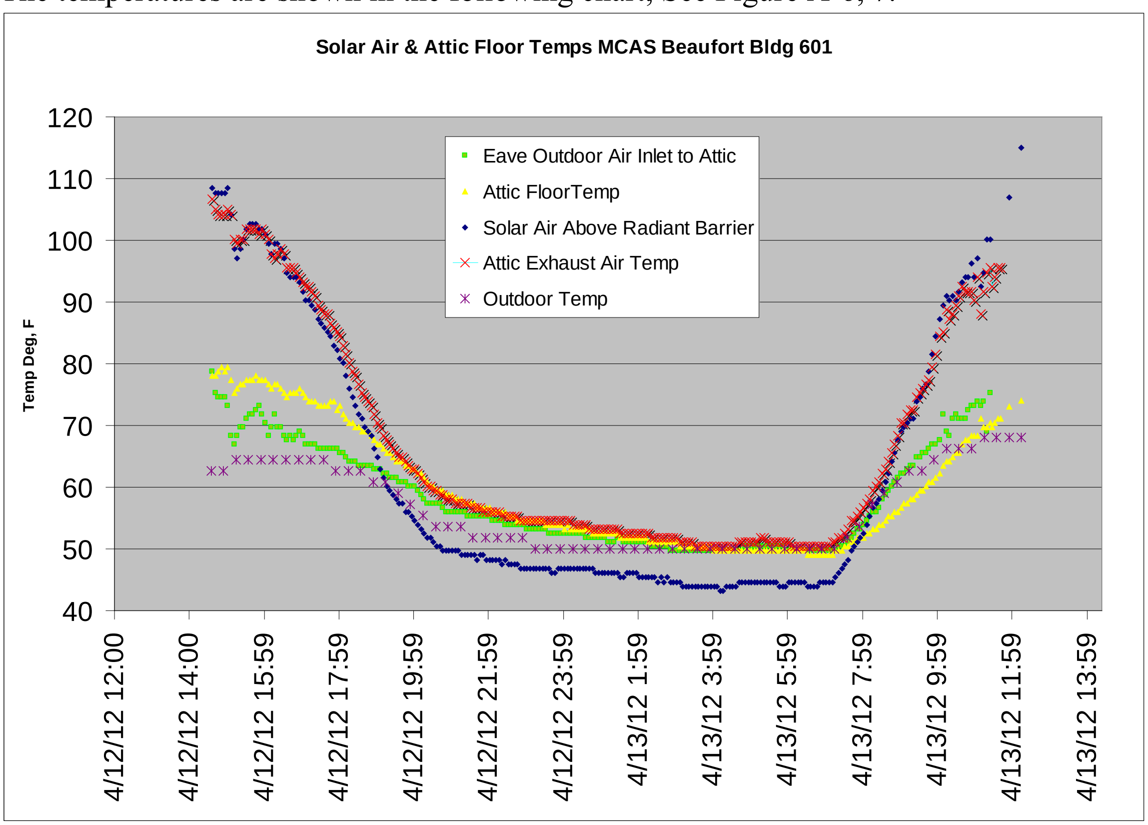

Figure A-6, 7 Solar and Attic Temperatures

Over the 22 hour monitoring period, the solar air temperatures above the radiant barrier peaked at 40 degrees F above the attic floor temperature and 47F above outdoor air temperatures. Both of these temperature differences were probably exceeded later in the afternoon on April 13th, a few hours after the monitoring had stopped.

Had a solar heat recovery system been in place, the heat exchanger fluid pump would have run from about 10:00 to 16:00 to supply solar heat to a geothermal loop with an expected average ground return temperature of 80F. Calculations indicate that during the 6 hours, the system would have provided about 120,000 to 180,000 BTU per hour to the ground loop.

Additional Considerations

In late April, a decision was made to shift the focus of the geothermal system test from Building 601 to another geothermal heat pump project at MCAS Beaufort. As a result the solar heat recovery system heat exchangers and piping fluid system were not installed.

Reports from the staff on the base indicate that the top floor of the building is more comfortable with the radiant barrier systems installed. All those involved during the installation agreed that the radiant barrier provided a very noticeable heat reduction once installed. The effect was noticeable when moving along the attic from an area where the radiant barrier had been completed to an area not yet completed. A simple test of sticking a hand up through the joints at the unsealed seams between sheets of the radiant barrier demonstrated the temperature difference between the air above and below the radiant barrier.

During the nighttime hours the temperature above the radiant barrier dropped to about 6 degrees lower than the outdoor air temperature. This is thought to be a result of nighttime radiational cooling of the dark roof panels radiating heat to the clear sky. As the roof panels cool, the warmer old roof below loses heat from radiating heat toward the bottom of the metal roof panels. The radiant barrier helps to reflect that heat back down toward the old roof, preventing it from otherwise being lost and increasing heating expenses during the heating season. In addition, cold air convection currents set up below the cold metal roof panels, dropping cold air down from the bottom of the cold metal roof panels onto the top of the old roof below. The stratifying effect of the radiant barrier helps to block those convection currents, keeping the old roof warmer during the heating season.

The fact that the night time solar roof air temperatures dropped below that of outdoor air temperatures means that the solar heat recovery systems could provide cooling of the cold geothermal field during many winter nights. In fact, there will be many days of the year, when the solar roof heat recovery systems could be used during the day to charge the hot geothermal field and during the night to charge the cold geothermal field. This could potentially eliminate or reduce the size of the dry cooler used for charging the cold field.

Acknowledgements

American Solar appreciates the support of the following individuals for their assistance during the development and execution of this project:

- Clemson Investigators, Dr. Ron Falta and Dr. Fred Molz
- MCAS Energy Manager, Mr. Neil Tisdale
- ESTCP Project Manager, Dr. Jim Galvin

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   http://www.serdp.org/About-SERDP-and-ESTCP/About-ESTCP

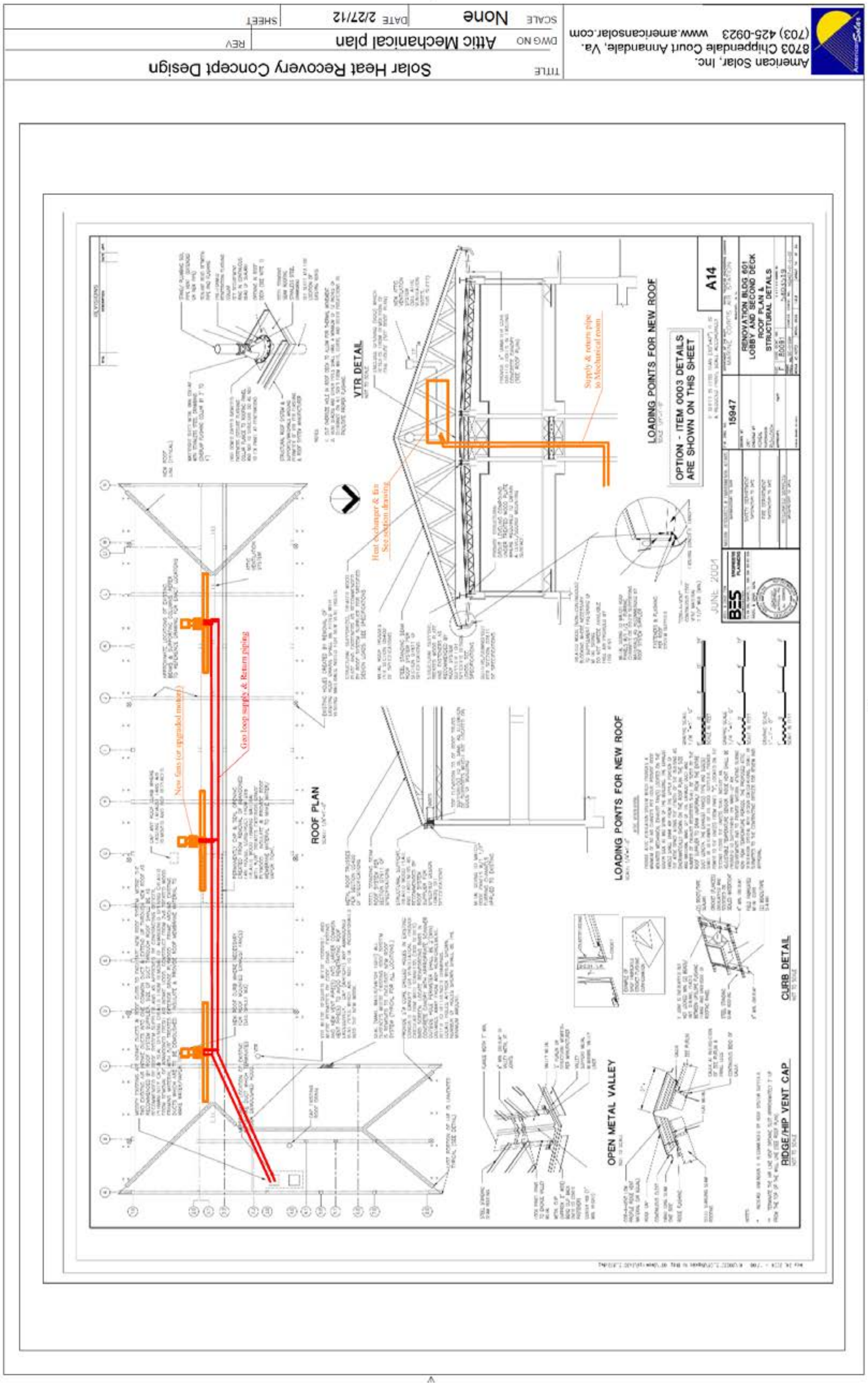

Figure A-6, 8 Solar Heat Recovery Piping for Geothermal

APPENDIX B: BUILDING LIFE CYCLE COST MODEL RESULTS

American Solar conducted a life cycle cost analysis of the Gaffney Solar re-roof in two ways. One used a conventional, 30 year discounted cash flow of the roofing expenses and the energy expenses for the "as built" case and of the "maximum savings" case. The other approach used the BLCC computer program with the same cost inputs over the 30 year life. The difference is in the escalation values assigned by BLCC as opposed to the OMB and NIST factors available for the discounted cash flow method. As a result, the BLCC program uses higher escalation values for the out year roofing expenses and salvage value at the end of the 30 year life. This results in higher savings for the solar roof than the discounted cash flow method.

Figure B-1, presents results from a BLCC analysis of the maximum savings case. This graph shows the cost of the roof and energy for the case where the Non-solar BURS are installed for 30 years, along with a case where the solar re-roof is installed. The cumulative discounted cost of each roofing system is shown as well as the combined cost of roofing and energy expenses. For example, the "Total BLCC, Non-Solar cash flow, roof only" case shows the cost of purchasing a new BUR in year 1, repairing it in year 13, recovering it in year 17, and repeating the process through year 30. The "Total BLCC cash flow Non-Solar BURs & Gas Cost" curve shows the combined BUR roof and gas energy costs over the 30 year period. The gas energy costs shown are equal to the gas that would have been required to offset the same energy saved by solar. The total 30 year expense for this analysis is $456,601 ($301,079 for roofing and $155,523 for gas). In contrast, the "Total BLCC Solar Roof & Elec Costs" curve results in a net 30 year expense of $185,546, a savings of $271,055 compared to the continued non-solar roofs.

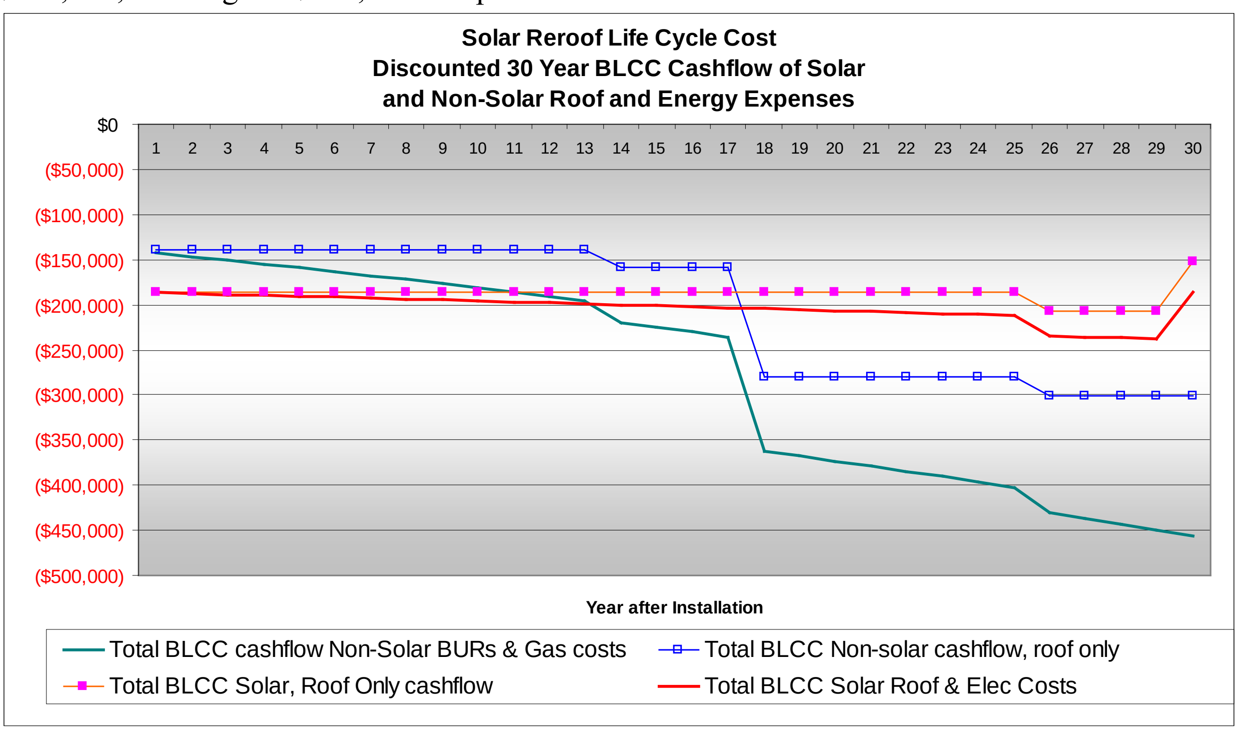

Figure B, 1 30 Year BLCC Life Cycle Cost

With the exception of the references to the BLCC calculation in section 6 of the report and in this appendix, all references to the energy and roofing cost savings in the report use the more conservative values from the separate discounted life cycle cost analysis using the NIST and OMB indices. As a comparison, the report projects a 30 year life cycle cost savings from roof and energy of only $188,698 vs. the $271,055 projected by the BLCC approach. This conservative savings estimate is still substantial enough to fully pay for another roof at the end of the life of the solar metal roof.

The BLCC output below incorporates the raw output and calculated values of cumulative cash flow using those BLCC output. Values in red are calculated values using the BLCC outputs

NIST BLCC 5.3-12: Cash Flow Analysis

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

General Information

File Name:	C:\Users\John Archibald\Desktop\Gaffney 2.xml
Date of Study:	Tue Mar 05 14:57:34 EST 2013
Analysis Type:	MILCON Analysis, Energy Project
Project Name:	Gaffney Solar Re-roof
Project Location:	Maryland
Analyst:	Archibald
Comment:	Solar air heating metal re-roof of Gaffney Fitnes Center, Max Savings Case, Fort Meade, MD
Base Date:	1-Jan-13
Beneficial Occupancy Date:	1-Jan-13
Study Period:	30 years 0 months (January 1, 2013 through December 31, 2042)

Mid-year cash-flow convention used

All costs in current dollars (including general inflation)

Alternative: As Is, with a Series of Non- Solar Built Up Roofs

Initial Capital Costs

Component: Non-solar BUR yr 1

Year Beginning	Total
Jan-13	$139,125
Total	$139,125

Capital Investment Costs

Year Beginning	Initial	Replacement	Total	Total BLCC Non-solar cashflow, roof only
Jan-13	$139,125	$0	$139,125	($139,125)
Jan-14	$0	$0	$0	($139,125)
Jan-15	$0	$0	$0	($139,125)
Jan-16	$0	$0	$0	($139,125)
Jan-17	$0	$0	$0	($139,125)
Jan-18	$0	$0	$0	($139,125)
Jan-19	$0	$0	$0	($139,125)
Jan-20	$0	$0	$0	($139,125)
Jan-21	$0	$0	$0	($139,125)
Jan-22	$0	$0	$0	($139,125)
Jan-23	$0	$0	$0	($139,125)
Jan-24	$0	$0	$0	($139,125)
Jan-25	$0	$0	$0	($139,125)
Jan-26	$0	$19,793	$19,793	($158,918)
Jan-27	$0	$0	$0	($158,918)
Jan-28	$0	$0	$0	($158,918)
Jan-29	$0	$0	$0	($158,918)
Jan-30	$0	$121,148	$121,148	($280,066)
Jan-31	$0	$0	$0	($280,066)
Jan-32	$0	$0	$0	($280,066)
Jan-33	$0	$0	$0	($280,066)
Jan-34	$0	$0	$0	($280,066)
Jan-35	$0	$0	$0	($280,066)
Jan-36	$0	$0	$0	($280,066)
Jan-37	$0	$0	$0	($280,066)
Jan-38	$0	$21,013	$21,013	($301,079)
Jan-39	$0	$0	$0	($301,079)
Jan-40	$0	$0	$0	($301,079)
Jan-41	$0	$0	$0	($301,079)
Jan-42	$0	$0	$0	($301,079)
Total	$139,125	$161,954	$301,079	

Operating-Related Costs

Year Beginning	Energy Consumption	Energy Demand	Energy Rebate	Total
Jan-13	$4,016	$0	$0	$4,016
Jan-14	$4,008	$0	$0	$4,008
Jan-15	$4,040	$0	$0	$4,040
Jan-16	$4,059	$0	$0	$4,059
Jan-17	$4,092	$0	$0	$4,092
Jan-18	$4,141	$0	$0	$4,141
Jan-19	$4,217	$0	$0	$4,217
Jan-20	$4,313	$0	$0	$4,313
Jan-21	$4,435	$0	$0	$4,435
Jan-22	$4,570	$0	$0	$4,570
Jan-23	$4,691	$0	$0	$4,691
Jan-24	$4,790	$0	$0	$4,790
Jan-25	$4,890	$0	$0	$4,890
Jan-26	$4,983	$0	$0	$4,983
Jan-27	$5,077	$0	$0	$5,077
Jan-28	$5,156	$0	$0	$5,156
Jan-29	$5,240	$0	$0	$5,240
Jan-30	$5,329	$0	$0	$5,329
Jan-31	$5,420	$0	$0	$5,420
Jan-32	$5,519	$0	$0	$5,519
Jan-33	$5,633	$0	$0	$5,633
Jan-34	$5,806	$0	$0	$5,806
Jan-35	$5,985	$0	$0	$5,985
Jan-36	$6,126	$0	$0	$6,126
Jan-37	$6,221	$0	$0	$6,221
Jan-38	$6,342	$0	$0	$6,342
Jan-39	$6,471	$0	$0	$6,471
Jan-40	$6,543	$0	$0	$6,543
Jan-41	$6,646	$0	$0	$6,646
Jan-42	$6,764	$0	$0	$6,764
Total	$155,523	$0	$0	$155,523

Sum of All Cash Flows

Year Beginning	Capital	OM&R	Total	Total BLCC cashflow Non-Solar BURs & Gas costs
Jan-13	$139,125	$4,016	$143,141	($143,141)
Jan-14	$0	$4,008	$4,008	($147,149)
Jan-15	$0	$4,040	$4,040	($151,189)
Jan-16	$0	$4,059	$4,059	($155,248)
Jan-17	$0	$4,092	$4,092	($159,340)
Jan-18	$0	$4,141	$4,141	($163,481)
Jan-19	$0	$4,217	$4,217	($167,698)
Jan-20	$0	$4,313	$4,313	($172,011)
Jan-21	$0	$4,435	$4,435	($176,446)
Jan-22	$0	$4,570	$4,570	($181,016)
Jan-23	$0	$4,691	$4,691	($185,707)
Jan-24	$0	$4,790	$4,790	($190,497)
Jan-25	$0	$4,890	$4,890	($195,387)
Jan-26	$19,793	$4,983	$24,775	($220,162)
Jan-27	$0	$5,077	$5,077	($225,239)
Jan-28	$0	$5,156	$5,156	($230,395)
Jan-29	$0	$5,240	$5,240	($235,635)
Jan-30	$121,148	$5,329	$126,477	($362,112)
Jan-31	$0	$5,420	$5,420	($367,532)
Jan-32	$0	$5,519	$5,519	($373,051)
Jan-33	$0	$5,633	$5,633	($378,684)
Jan-34	$0	$5,806	$5,806	($384,490)
Jan-35	$0	$5,985	$5,985	($390,475)
Jan-36	$0	$6,126	$6,126	($396,601)
Jan-37	$0	$6,221	$6,221	($402,822)
Jan-38	$21,013	$6,342	$27,355	($430,177)
Jan-39	$0	$6,471	$6,471	($436,648)
Jan-40	$0	$6,543	$6,543	($443,191)
Jan-41	$0	$6,646	$6,646	($449,837)
Jan-42	$0	$6,764	$6,764	($456,601)
Total	$301,079	$155,523	$456,602	

Alternative: Solar Re-roof Max Savings Case

Initial Capital Costs

Component: Solar metal air heating reroof system

Year Beginning	Total
Jan-13	$185,500
Total	$185,500

Capital Investment Costs

Year Beginning	Initial	Residual (Orig. Comp.)	Replacement	Total	Total BLCC Solar, Roof Only cashflow
Jan-13	$185,500	$0	$0	$185,500	($185,500)
Jan-14	$0	$0	$0	$0	($185,500)
Jan-15	$0	$0	$0	$0	($185,500)
Jan-16	$0	$0	$0	$0	($185,500)
Jan-17	$0	$0	$0	$0	($185,500)
Jan-18	$0	$0	$0	$0	($185,500)
Jan-19	$0	$0	$0	$0	($185,500)
Jan-20	$0	$0	$0	$0	($185,500)
Jan-21	$0	$0	$0	$0	($185,500)
Jan-22	$0	$0	$0	$0	($185,500)
Jan-23	$0	$0	$0	$0	($185,500)
Jan-24	$0	$0	$0	$0	($185,500)
Jan-25	$0	$0	$0	$0	($185,500)
Jan-26	$0	$0	$0	$0	($185,500)
Jan-27	$0	$0	$0	$0	($185,500)
Jan-28	$0	$0	$0	$0	($185,500)
Jan-29	$0	$0	$0	$0	($185,500)
Jan-30	$0	$0	$0	$0	($185,500)
Jan-31	$0	$0	$0	$0	($185,500)
Jan-32	$0	$0	$0	$0	($185,500)
Jan-33	$0	$0	$0	$0	($185,500)
Jan-34	$0	$0	$0	$0	($185,500)
Jan-35	$0	$0	$0	$0	($185,500)
Jan-36	$0	$0	$0	$0	($185,500)
Jan-37	$0	$0	$0	$0	($185,500)
Jan-38	$0	$0	$21,013	$21,013	($206,513)
Jan-39	$0	$0	$0	$0	($206,513)
Jan-40	$0	$0	$0	$0	($206,513)
Jan-41	$0	$0	$0	$0	($206,513)
Jan-42	$0	($53,859)	$0	($53,859)	($152,654)
Total	$185,500	($53,859)	$21,013	$152,654	

Operating-Related Costs

Year Beginning	Energy Consumption	Energy Demand	Energy Rebate	Total
Jan-13	$994	$0	$0	$994
Jan-14	$1,005	$0	$0	$1,005
Jan-15	$1,018	$0	$0	$1,018
Jan-16	$1,023	$0	$0	$1,023
Jan-17	$1,023	$0	$0	$1,023
Jan-18	$1,024	$0	$0	$1,024
Jan-19	$1,023	$0	$0	$1,023
Jan-20	$1,028	$0	$0	$1,028
Jan-21	$1,035	$0	$0	$1,035
Jan-22	$1,042	$0	$0	$1,042
Jan-23	$1,051	$0	$0	$1,051
Jan-24	$1,057	$0	$0	$1,057
Jan-25	$1,061	$0	$0	$1,061
Jan-26	$1,065	$0	$0	$1,065
Jan-27	$1,070	$0	$0	$1,070
Jan-28	$1,075	$0	$0	$1,075
Jan-29	$1,078	$0	$0	$1,078
Jan-30	$1,085	$0	$0	$1,085
Jan-31	$1,095	$0	$0	$1,095
Jan-32	$1,105	$0	$0	$1,105
Jan-33	$1,115	$0	$0	$1,115
Jan-34	$1,133	$0	$0	$1,133
Jan-35	$1,153	$0	$0	$1,153
Jan-36	$1,173	$0	$0	$1,173
Jan-37	$1,190	$0	$0	$1,190
Jan-38	$1,206	$0	$0	$1,206
Jan-39	$1,224	$0	$0	$1,224
Jan-40	$1,236	$0	$0	$1,236
Jan-41	$1,247	$0	$0	$1,247
Jan-42	$1,258	$0	$0	$1,258
Total	$32,891	$0	$0	$32,891

Sum of All Cash Flows

Year Beginning	Capital	OM&R	Total	Total BLCC Solar max savings case	Total BLCC Solar Roof & Elec Costs
Jan-13	$185,500	$994	$186,494	($186,494)	($186,494)
Jan-14	$0	$1,005	$1,005	($183,491)	($187,499)
Jan-15	$0	$1,018	$1,018	($180,469)	($188,517)
Jan-16	$0	$1,023	$1,023	($177,433)	($189,540)
Jan-17	$0	$1,023	$1,023	($174,364)	($190,563)
Jan-18	$0	$1,024	$1,024	($171,247)	($191,587)
Jan-19	$0	$1,023	$1,023	($168,053)	($192,610)
Jan-20	$0	$1,028	$1,028	($164,768)	($193,638)
Jan-21	$0	$1,035	$1,035	($161,368)	($194,673)
Jan-22	$0	$1,042	$1,042	($157,840)	($195,715)
Jan-23	$0	$1,051	$1,051	($154,200)	($196,766)
Jan-24	$0	$1,057	$1,057	($150,467)	($197,823)
Jan-25	$0	$1,061	$1,061	($146,638)	($198,884)
Jan-26	$0	$1,065	$1,065	($142,720)	($199,949)
Jan-27	$0	$1,070	$1,070	($138,713)	($201,019)
Jan-28	$0	$1,075	$1,075	($134,632)	($202,094)
Jan-29	$0	$1,078	$1,078	($130,470)	($203,172)
Jan-30	$0	$1,085	$1,085	($126,226)	($204,257)
Jan-31	$0	$1,095	$1,095	($121,901)	($205,352)
Jan-32	$0	$1,105	$1,105	($117,487)	($206,457)
Jan-33	$0	$1,115	$1,115	($112,969)	($207,572)
Jan-34	$0	$1,133	$1,133	($108,296)	($208,705)
Jan-35	$0	$1,153	$1,153	($103,464)	($209,858)
Jan-36	$0	$1,173	$1,173	($98,511)	($211,031)
Jan-37	$0	$1,190	$1,190	($93,480)	($212,221)
Jan-38	$21,013	$1,206	$22,219	($109,357)	($234,440)
Jan-39	$0	$1,224	$1,224	($104,110)	($235,664)
Jan-40	$0	$1,236	$1,236	($98,803)	($236,900)
Jan-41	$0	$1,247	$1,247	($93,404)	($238,147)
Jan-42	($53,859)	$1,258	($52,601)	($34,039)	($185,546)
Total	$152,654	$32,891	$185,546		

NIST BLCC 5.3-12: Comparative Analysis

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

Base Case: As Is, with a Series of Non- Solar Built Up Roofs

Alternative: Solar Re-roof Max Savings Case

General Information

File Name:	C:\Users\John Archibald\Desktop\Gaffney 2.xml
Date of Study:	Tue Mar 05 17:17:39 EST 2013
Project Name:	Gaffney Solar Re-roof
Project Location:	Maryland
Analysis Type:	MILCON Analysis, Energy Project
Analyst:	Archibald
Comment	Solar air heating metal re-roof of Gaffney Fitness Center, Max Savings Case, Fort Meade, MD
Base Date:	1-Jan-13
Beneficial Occupancy Date:	1-Jan-13
Study Period:	30 years 0 months(January 1, 2013 through December 31, 2042)
Discount Rate:	3.50%
Discounting Convention:	Mid-Year

Comparison of Present-Value Costs

PV Life-Cycle Cost

	Base Case	Alternative	Savings from Alternative
Initial Investment Costs:			
Capital Requirements as of Base Date	$139,125	$185,500	($46,375)
Future Costs:			
Energy Consumption Costs	$92,244	$20,122	$72,122
Energy Demand Charges	$0	$0	$0
Energy Utility Rebates	$0	$0	$0
Water Costs	$0	$0	$0
Routine Recurring and Non-Recurring OM&R Costs	$0	$0	$0
Major Repair and Replacements	$89,053	$8,892	$80,162
Residual Value at End of Study Period	$0	($19,191)	$19,191
	------------	------------	------------
Subtotal (for Future Cost Items)	$181,298	$9,822	$171,475
	------------	------------	------------
Total PV Life-Cycle Cost	$320,423	$195,322	$125,100

Net Savings from Alternative Compared with Base Case

PV of Non-Investment Savings	$72,122
- Increased Total Investment	-$52,978

Net Savings	$125,100

NOTE: Meaningful SIR, AIRR and Payback can not be computed unless incremental savings and total savings are both positive.

Energy Savings Summary

Energy Savings Summary (in stated units)

Energy Type	-----Average Base Case	Annual Alternative	Consumption----- Savings	Life-Cycle Savings
Electricity	0.0 kWh	8,613.0 kWh	-8,613.0 kWh	-258,354.6 kWh
Natural Gas	460.0 MBtu	0.0 MBtu	460.0 MBtu	13,798.1 MBtu

Energy Savings Summary (in MBtu)

Energy Type	-----Average Base Case	Annual Alternative	Consumption----- Savings	Life-Cycle Savings
Electricity	0.0 MBtu	29.4 MBtu	-29.4 MBtu	-881.5 MBtu
Natural Gas	460.0 MBtu	0.0 MBtu	460.0 MBtu	13,798.1 MBtu

Emissions Reduction Summary

Energy Type		-----Average Base Case	Annual Alternative	Emissions----- Reduction	Life-Cycle Reduction
Electricity					
	CO2	0.00 kg	5,631.14 kg	-5,631.14 kg	-168,911.09 kg
	SO2	0.00 kg	28.38 kg	-28.38 kg	-851.14 kg
	NOx	0.00 kg	8.40 kg	-8.40 kg	-252.09 kg
Natural Gas					
	CO2	24,298.74 kg	0.00 kg	24,298.74 kg	728,862.29 kg
	SO2	196.10 kg	0.00 kg	196.10 kg	5,882.15 kg
	NOx	7.28 kg	0.00 kg	7.28 kg	218.40 kg
Total:					
	CO2	24,298.74 kg	5,631.14 kg	18,667.60 kg	559,951.20 kg
	SO2	196.10 kg	28.38 kg	167.72 kg	5,031.01 kg
	NOx	7.28 kg	8.40 kg	-1.12 kg	-33.69 kg

APPENDIX C: MANAGEMENT AND STAFFING

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone Fax E-mail	Role in Project
John Archibald	American Solar, Inc. 8703 Chippendale Court Annandale, Virginia 22003	Phone: (703) 346-6053 Fax: (703) 425-2047 JArchibald@americansolar.com	Principal Investigator (PI)
Tony Karwoski	Sain Engineering Dept. of Public Works Ft. Meade, Maryland 20755	Phone: (301) 677-9353 Anthony.K.Karwoski.ctr@mail.mil	Ft. Meade Resource Efficiency Manager
Bill Stein	Engineer Research and Development Center - Construction Engineering Research Laboratory, U.S. Army Corps of Engineers Champaign, Illinois 61822	Phone: (520) 533-1861 William.J.Stein@usace.army.mil	Research Mechanical Engineer

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